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THE HYDROLOGIC ROLE OF THE UNSATURATED ZONE OF A FORESTED COLLUVIUM-MANTLED HOLLOW REDWOOD NATIONAL PARK, CALIFORNIA

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RESEARCH AND DEVELOPMENT

TECHNICAL REPORT 26
AUGUST 1990

GROUNDWATER MONITORING PROJECT

In 1981, Redwood National Park began a series of projects to examine the relationships between precipitation, groundwater, and mass movement. The purposes of these projects were to: 1) add to the existing body of scientific information on this topic, and 2) provide guidelines to watershed rehabilitation activities related to landslide and road fill stabilization. The study described here was one of several masters theses which comprise important elements of the groundwater monitoring project.

NOTICE

This document contains information of a preliminary nature, and was prepared primarily on an interim basis. This information may be revised or updated.

THE HYDROLOGIC ROLE OF THE UNSATURATED ZONE OF A FORESTED COLLUVIUM-MANTLED HOLLOW REDWOOD NATIONAL PARK, CALIFORNIA

Redwood National Park Research and Development

Technical Report Number 26

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ABSTRACT

The hydrologic behavior of the unsaturated zone of a forested colluvium-mantled hollow was examined using an array of 11 tensiometers and 3 groundwater wells to record the response to rainfall events during the 1987-88 winter. Erratic tensiometer responses, including inverted soil profile wetting, indicate that at the onset of the rainfall season, when the soil moisture content is relatively low and unsaturated hydraulic conductivity is low, the dominant mode of transport in the unsaturated zone is flow in macropores. Later in the rainfall season, when the soil mass is more uniformly wetted, a uniform tensiometer response indicates that translatory flow is the dominant transport mechanism. Rapid and disproportionate rises in the water table result when small amounts of infiltrating water encounter a thick capillary fringe, where water is held in the soil pores above field capacity. The hydrologic behavior of the unsaturated zone of a forested soil plays a significant role in drainage basin response time to storms. No evidence was found to indicate that the hydrology of the unsaturated zone of a colluvium-mantled hollow differs from that of any other forest soil environment.

ACKNOWLEDGEMENTS

Many people helped make this report what it is. For field assistance in some wet and windy conditions as well as day to day discussions Terese (I got the accents) Abelli was invaluable and a true buddy. Andre Lehre was helpful through the entire process and almost always approached questions and consultation with enthusiasm. Robert Willis provided stability and focus with his calm efficiency. Both of these professors seemed to always have time for me, thank you. Thanks to Lori Dengler for efficient, thoughtful and timely draft reviews. Bill Weaver, Ron Sonnevil, and Randy Klein helped me to choose this topic and location and aided with much of the field instrumentation. Thanks to Kevin O'Dea and Mike Napolitano who helped in the field.

Finally, this is dedicated to my parents, Robert H. Amen and Carol V. Amen, who both died unexpectedly during my work on this thesis. I remember you daily.

I. INTRODUCTION

A colluvium-mantled hollow is a bedrock depression on a hillslope filled or partially filled with soil and rock debris that has moved downslope under the force of gravity (Dietrich and Dunne, 1978). The geomorphic importance of colluvium-mantled hollows to hillslope evolution is well documented (Dietrich and Dunne, 1978; Lehre, 1982; Dietrich, Reneau, and Wilson, 1987). The unsaturated zone of forested colluvium-mantled hollows is important for two main reasons.

First, the unsaturated zone, through which most rainfall travels, plays a role in the stability of colluvial fill because an increase in soil moisture content generally decreases soil strength (Sowers and Royster, 1978). Colluvium-mantled hollows (also referred to as swales or zero-order basins) are common sites of debris flow initiation. LaHusen (1984) documents 40 debris flows that occurred in the Redwood Creek basin during the 1981-82 rainfall season. He reports that 58% of these debris flows originated in swales at the heads of ephemeral drainages. Since catastrophic failure by debris flow is almost always related to a precipitation event, an understanding of the subsurface hydrology is important. The unsaturated zone is a part of the subsurface hydrologic regime of colluvial hollows that has received little attention.

Second, the unsaturated zone affects basin-wide hydrology. It is now generally accepted that subsurface stormflow, not overland flow, is the major component of total stormflow in most forested drainages (Hursh, 1944; Whipkey, 1967; Hewlett and Hibbert, 1967; Weyman, 1973). The rate of flow through the subsurface is the primary control on drainage basin response to storm events. Abdul and Gillham (1984) report that a rising water table can cause the rapid generation of hydraulic gradients directed to the toe of the slope causing immediate flow of groundwater to the stream. If flow to the stream occurs almost immediately upon a water table rise, only the unsaturated zone can cause a significant lag time between rainfall and streamflow response.

The mode of transport through the unsaturated zone is important because 1) it can affect the amount of moisture stored in the soil mantle, and therefore affect slope stability and 2) it determines the travel time through the unsaturated zone to the water table, and therefore effects drainage basin response time.

II. OBJECTIVES

The objectives of this investigation were 1) to determine the dominant mode of moisture transport in the unsaturated zone in a forested colluvial hollow, 2) to determine the cause for observed rapid and disproportionate rises (with respect to expected rises based on the specific yield of the soil) in the water table during storm events monitored by previous investigators (Sonnevil, 1987), and 3) to compare moisture transport through the unsaturated zone of a colluvial hollow with other environments.

III. PREVIOUS STUDIES

Colluvium-mantled hollows have been studied extensively in recent years. Their importance to hillslope evolution has been discussed by Dietrich and Dunne (1978), Lehre (1982), Dietrich and Dorn (1984), Marron (1985), Kelsey (1985), Reid (1985) and Dietrich, Reneau, and Wilson (1987). Specific research includes studies on the rates of evacuation by debris flow (Reneau and Dietrich, 1985), the rates of infilling (Lehre, 1987), and bedrock geometry (Dengler, et al., 1987). Additional research has focused on the groundwater hydrology of bedrock hollows (Hayes, 1985; Wilson and Dietrich, 1987; Tsukamoto and Minematsu, 1987). Since it is widely recognized that elevated groundwater levels cause elevated pore water pressures, and consequent reduction of slope stability (Campbell, 1975; Caine, 1980), the groundwater hydrology of colluvium-mantled hollows and its relationship to slope stability and debris flow generation has also been studied (Pierson, 1977; Humphrey, 1982; Sidle, 1987).

Few investigations of colluvium-mantled hollows have focused on moisture flow and storage in the unsaturated zone. Since rainfall must pass through the unsaturated zone in order to reach the water table (unless the water table intersects the ground surface), it is essential to understand the moisture transport mechanism in the unsaturated zone if groundwater responses are to be understood. Rainfall residence times and storm water flow velocities in the unsaturated zone affect the timing and amount of water that reaches the water table and therefore affect development of elevated pore water pressures.

A number of studies of the unsaturated zone in other forest environments have been reported (Horton and Hawkins, 1964; Hewlett and Hibbert, 1967; Whipkey, 1967; Aubertin, 1971; Mosely, 1982). Two mechanisms of how moisture travels through the unsaturated zone have been proposed. Horton and Hawkins (1964) and Hewlett and Hibbert (1967), working on a sloping forest soil, contend that new or event water (precipitation from the current storm) slowly traverses the unsaturated zone by displacing water already stored in the soil pores in a wave-like manner. This has been referred to as piston flow or translatory flow (Hewlett and Hibbert, 1967). Translatory flow can be demonstrated by draining a soil column to field capacity in the laboratory and then adding a small amount of water at the top. Water will flow from the bottom almost immediately, but it is clear that it is not the same water that was just added at the top. The small amount of water added displaces water stored in the soil and a rapid pulse moves quickly down the column.

Whipkey (1967), Aubertin (1971), Beasley (1976), and Mosely (1982), who also worked on forest soils, contend that event water traverses the unsaturated zone chiefly through macropores or along root channels. Chamberlin (1972) describes a forest soil of coastal British Columbia as an "open soil", through which most of the event water reaches the water table by paths other than through the matrix of the soil, usually by macropores. Extensive macropore or piping systems have been documented in colluvial hollows of coastal northern California (Ziemer and Albright, 1987). Mosely (1982) quantified infiltration rates for various forest soils in New Zealand, using an artificial rainfall simulator on field soils, and noted the importance of macropores in the rapid transmission of new water to the water table. Pearce, et al. (1986) argue, however, that macropore infiltration field experiments are unrealistic since high artificial rainfall rates are generally used, which could cause uncharacteristic saturation of the macropores.

Bonnell et al. (1983) suggest that both interstitial piston flow and rapid bypass or macropore flow can occur simultaneously. They believe that the relative importance of each mechanism is determined by the structure and moisture status of the soil. Regardless of the model chosen, Darcy's law cannot be easily applied to describe flow through the unsaturated zone of a forested soil mantle because of the heterogeneous nature of the soil hydraulic properties (Beven and Germann, 1982).

Translatory flow and macropore flow are mechanisms by which water can traverse the unsaturated zone, but they do not describe how disproportionate rises in the level of the water table can occur. It has been suggested that the characteristics of the capillary fringe (the zone of negative pressure saturation or near-saturation, usually just above the water table) can have an enormous effect on the level of the water table (Sklash and Farvolden, 1979; Gillham, 1984; Abdul and Gillham, 1984; Novakowski and Gillham, 1988). Since water in the capillary fringe is held above field capacity, rapid water table rise can occur when a small amount of water is added because the zone above the water table is already near positive pressure saturation. Gillham (1984) demonstrated in a controlled field experiment that the groundwater table could show a disproportionately large rise in response to rainfall if the capillary fringe extended to or near the ground surface. He reports that the addition of 0.3 cm of water caused the water table to rise 30 cm in 15 seconds.

IV. STUDY AREA

A. Location

The study area is located in Redwood National Park, northwestern California, (approximately 40 kilometers north of Eureka, California) near the town of Orick (Fig. 1). The site is located 500 meters north of the A-9 deck on the L-line logging road (Fig. 1). The site was chosen because of a previous landslide in a similar setting nearby and pre-existing instrumentation and monitoring of the site.

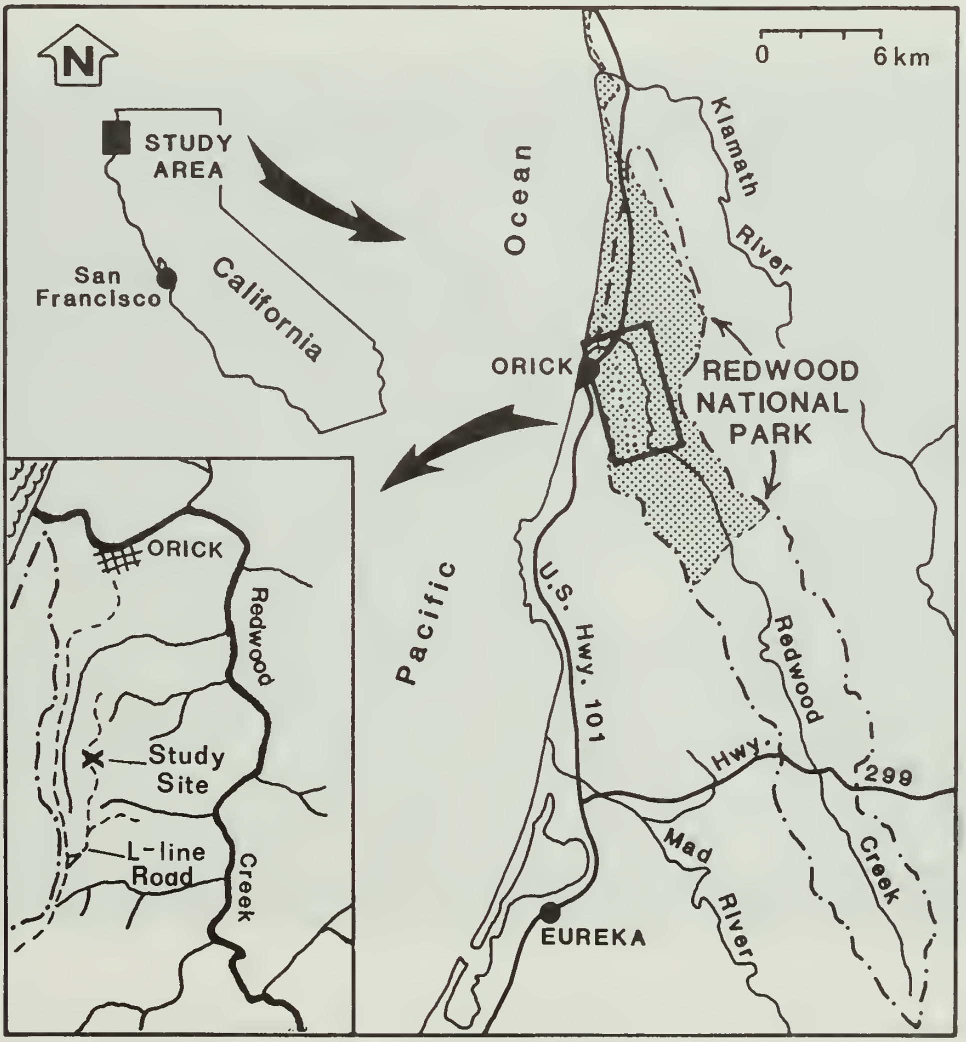


Figure 1. Location of Redwood National Park and study area.

In December 1981, a failure occurred within a colluvial hollow resulting in a large debris flow (2500 cubic meters) on the L-line logging road (Fig. 2). In 1983, an adjacent, morphologically similar swale (Fig. 2) on the L-line road was chosen as the site for a groundwater hydrology study by Sonnevil and LaHusen (1984). The site was instrumented with 24 piezometers, with ground water monitoring since 1984 by both intermittent manual observation and automated continuous recorders. In 1987, instrumentation was added for this study to investigate the hydrologic characteristics of the unsaturated zone.

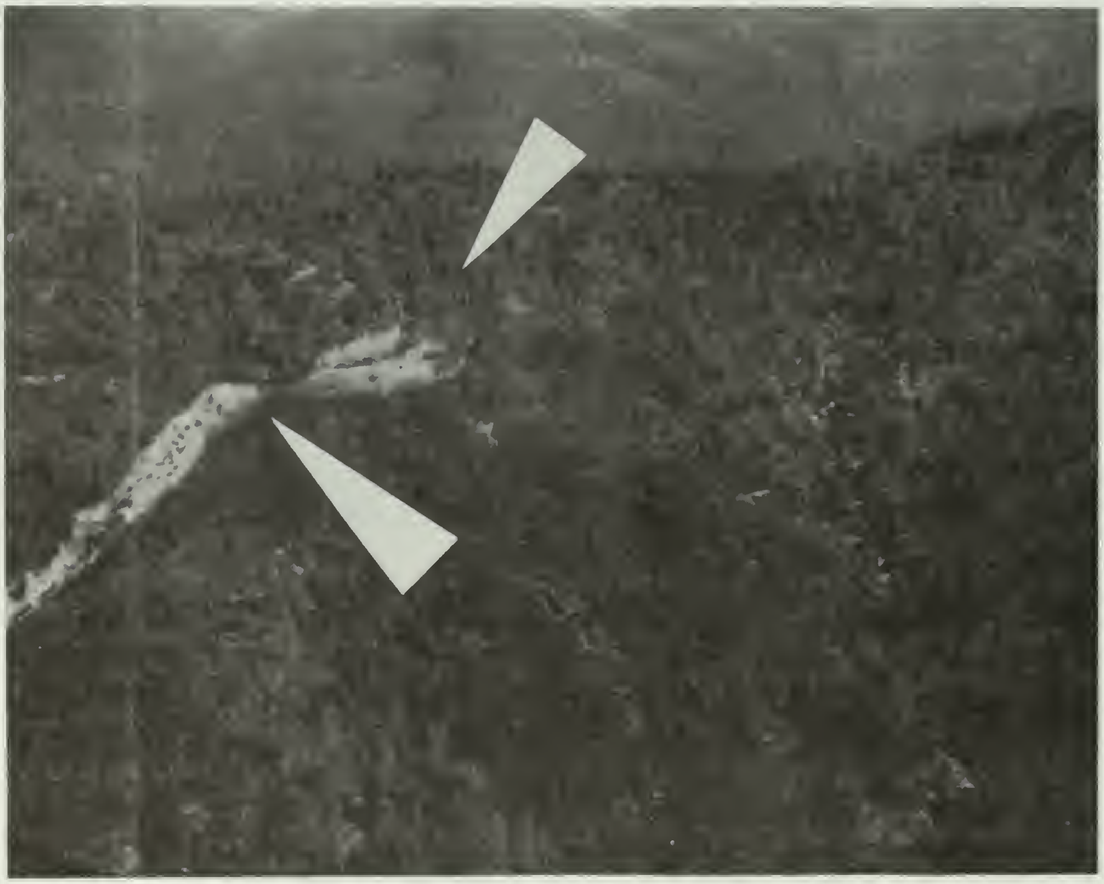


Figure 2. A 2500 cubic meter debris flow (large arrow) occurred on the L-line logging road in December 1981. The unsaturated zone of the adjacent colluvial hollow (small arrow) was investigated.

B. Geology

The Redwood Creek basin is part of a region that is experiencing rapid uplift. Janda et al. (1975) estimate that Redwood Creek has incised 0.4 - 1.3 mm/yr since the late Pleistocene. The basin is underlain, for the most part, by highly fractured and structurally weak sandstones and schists.

The study site is underlain by the Redwood Creek schist. The soil mantle has been described by Popenoe (1987) as the Coppercreek series, a fine-loamy, mixed, isomesic Typic Haplohumult (Fig. 3). The soil, which averages 132 cm thick, contains abundant macropores and roots in the upper 100 cm.

C. Geomorphology

The combination of rapid tectonic uplift, abundant intense rainfall, and sheared bedrock makes much of the terrain in Redwood National Park highly erodible, deeply incised, and generally rugged. The basin contains some of the most rapidly eroding terrain in North America (Janda and Nolan, 1979).

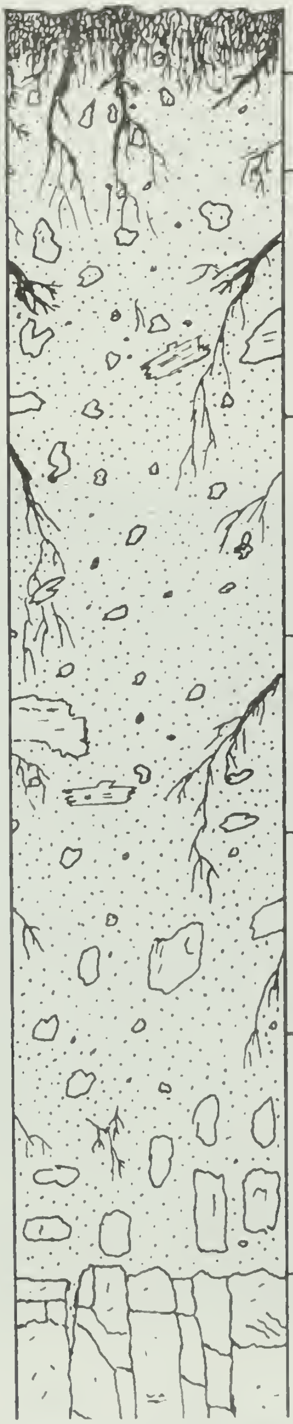
Colluvial deposits in bedrock hollows are common on the upper hillslopes of the Redwood Creek basin. The geometry and distribution of the hollows suggest that they result from landsliding and are characterized by alternating episodes of filling and emptying (Marron, 1985). Intervening periods of slope stability allow for the development of soils on the colluvium.

The colluvium-mantled hollow described in this investigation is located on an upper mountain hillslope (Fig. 4) at an elevation of 410 meters. The hollow faces N50W with a mean gradient of approximately 25 degrees. The swale has a basin area of approximately 1800 square meters (Fig. 5).

D. Climate

The climate of Redwood National Park is coastal Mediterranean, characterized by mild rainy winters and rainless but foggy summers. Mean annual precipitation is approximately 200 cm, most of which falls between September and April.

Precipitation, which has been monitored at the study site since 1984, averages 170 cm annually, with maximum measured rainfall intensities of 1.5 cm/hr (precipitation from 12/2/87 to 3/19/88 is on page 27). Light snow occasionally falls at the study site, but rarely develops a snowpack and generally melts within a few days.



Depth (cm)	Horizon	Description
	O	Decomposing forest liter.
6		
	A	Dark brown (7.5 YR 3/4) silty loam (12% gravel), weak fine and medium subangular blocky structure, many very fine and fine roots, few medium and coarse roots.
17		
	AB	Dark reddish brown (5 YR 3/4) gravelly silty loam (20% gravel), weak fine and medium subangular blocky structure, common very fine, fine, medium, and coarse roots.
40		
	BAt	Yellowish red (5 YR 4/6) gravelly silty clay loam (10% gravel), weak coarse and very coarse subangular blocky, common very fine, fine, medium, and coarse roots.
65		
	Bt	Yellowish red (5 YR 4/6) silty clay loam (10% gravel), weak coarse and very coarse subangular blocky, few very fine, fine, medium and coarse roots.
84		
	BC	Strong brown (7.5 YR 5/6) gravelly silty clay loam (15% gravel), weak coarse and very coarse subangular blocky, few very fine and fine roots.
117		
	C	Strong brown (7.5 YR 5/8) gravelly silty clay loam (20% gravel), massive, few very fine and fine roots.
132		
	Cr+R	Weathered Schist

Figure 3. Soil profile description of soil pit #1 (Popenoe, 1987). The location of the soil pit is shown in Figure 8.

Figure 4. Looking up the sideslope of the swale showing topography and vegetation. Tensiometers and groundwater wells are also shown.

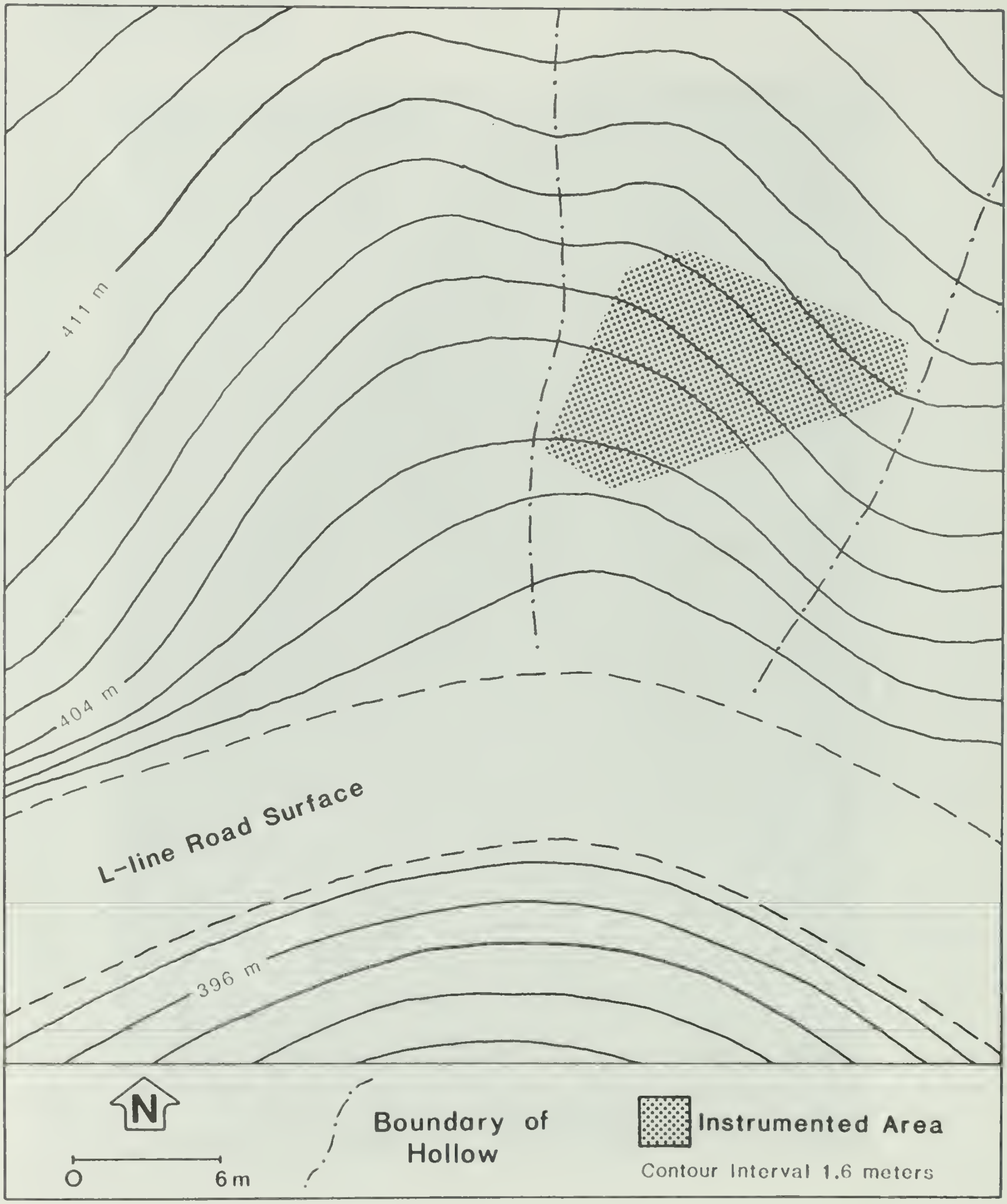


Figure 5. Topography of colluvium-mantled hollow.

E. Vegetation

Redwood National Park contains a multitude of vegetative environments, from dry prairies to swampy wetlands. The dominant type of vegetation, however, is old growth and second growth conifer forest. The study site is located within a typical second growth forest (Fig. 4) consisting of redwood (Sequoia sempervirens), Douglas fir (Pseudotsuga menziesii), tanoak (Lithocarpus densiflora), and red alder (Alnus oregona), most of which are younger than 20 years in age. The understory is comprised of coast rhododendron (Rhododendron macrophyllum), black huckleberry (Vaccinium ovatum), salal (Gaultheria shallon), wax myrtle (Myrica californica), and red huckleberry (Vaccinium ovatum).

F. Land Use History

Before the Redwood Creek basin was acquired by the National Park Service in 1978, it was logged extensively by private timber companies. The study site is located just upslope of a major logging haul road that was built in the late 1960's (Fig. 6). The area was clear cut and tractor yarded of old

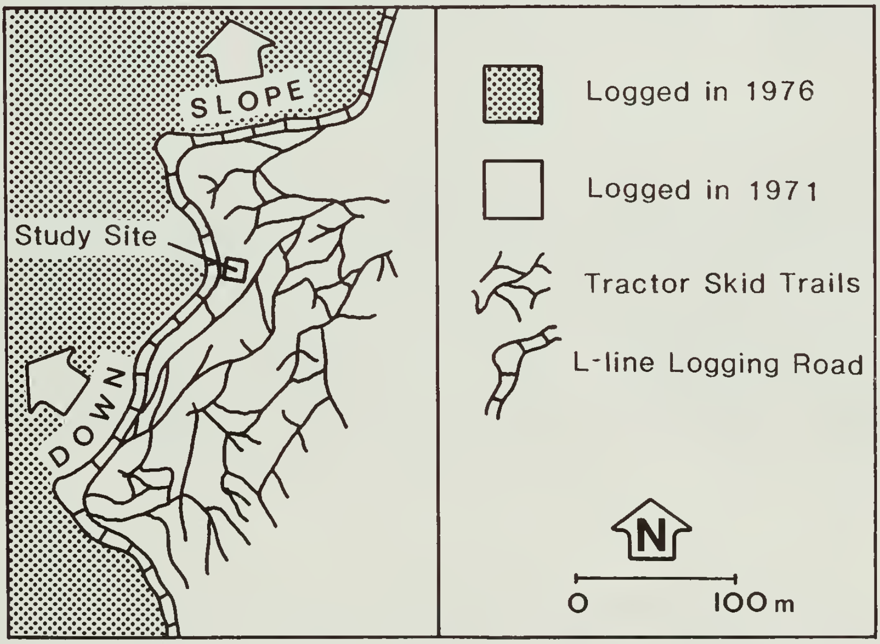


Figure 6. Land use of study site and surrounding area. Note that tractor skid trails do not cross the study site.

growth conifers in 1971. Many tractor skid trails 3 to 6 meters in width cross the area both upslope and downslope of the L-line road, but air photo analysis indicates that no skid trails exist within the portion of the swale monitored in this investigation (Fig. 6). Therefore, compaction due to logging activities is considered to be minimal within the study site.

V. WATER BUDGET

Identifying the significant components of the water budget of the unsaturated zone is an important step in study design and in selecting appropriate field instrumentation. Several assumptions were made regarding the significance of potential unsaturated zone inflows and outflows.

A. Inflows

Water may enter the system from several sources including: infiltration of surface water (for example, overland flow or streamflow), lateral flow through the unsaturated zone from outside the study area, groundwater drawn into the unsaturated zone by capillary forces, and precipitation. The hollow was unchanneled and overland flow was not observed during the monitoring period, and so was considered negligible. Significant lateral unsaturated flow may occur if the unsaturated zone contains low permeability layers (Mosely, 1982) which create a perched zone of high moisture content that drains downslope. No such layer was observed in either of two soil pits, so no attempt was made to quantify lateral unsaturated flow. Groundwater input, if significant, can be observed using perforated groundwater wells. Precipitation was considered to be the most important input, since all the other inputs appear negligible.

B. Storage

Changes in soil moisture content in the unsaturated zone represent changes in system storage. Water is stored in the soil mantle by capillary tension (negative pressure), which is the predominant force that holds water in soil pores above the water table (Curtis and Trudgill, 1974). As water content increases and the soil pores become more filled with water, capillary tension decreases. When the force of gravity exceeds capillary tension in a pore, drainage of the pore occurs. Quantifying changes in soil moisture storage is essential in a hydrologic investigation of the unsaturated zone.

C. Outflows

System outflows may include evapotranspiration, direct flow to a stream from the unsaturated zone, lateral unsaturated flow downslope, and flow to the water table. Evapotranspiration was considered to be negligible because cool oceanic air of northwest coastal California lowers evapotranspiration to 80-90% below that of the interior

valleys (Nixon and Lawless, 1968). There are no streams within the swale, so streamflow was also considered negligible, as was lateral unsaturated flow (discussed above). Flow to the groundwater table was considered to be the only important outflow from the system, since all other outflows are assumed to be negligible.

VI. METHODS

To quantify the mode of transport through the unsaturated zone and to study the causes of rapid water table rise, data was collected on moisture inflows to the system, changes in soil moisture storage, and groundwater and soil water outflows.

A. Inflows

Precipitation was measured using a continuous recording rain gage, located 400 meters south of the monitored swale. The continuous record provided valuable information on short duration rainfall intensities during the study period.

B. Soil Moisture Storage

Tensiometers, which are designed to measure soil moisture tension, were used to indirectly measure soil moisture change in the unsaturated zone. The tensiometers were the standard porous cup type with mercury manometers (Fig. 7). The porous cup is placed at the level where soil moisture tension information is desired. The cup, connecting pipe, and nylon manometer tube are filled with deaired (recently boiled) water. The deaired water minimizes air bubbles that come out of solution as pressure within the tensiometer changes. This is an important consideration as air bubbles within the assembly may cause erroneous readings.

If the soil is not saturated, some soil suction or tension probably exists. This suction draws water out of the tensiometer through the porous walls of the ceramic cup, causing a rise in the mercury level until equilibrium is attained. When fluctuations in soil moisture content occur by drainage or rainfall, corresponding fluctuations in soil moisture tension are reflected by the mercury level in the manometer. The elevation difference between the mercury level and the porous cup must be carefully measured to correct for the tension exerted by the hanging column of water.

Because the soil was stony, it was necessary to auger holes for the tensiometers and subsequently backfill with sifted material to ensure good contact between the porous cup and the soil matrix. A rock in the insertion hole could damage the cup or cause erroneous tension values. The sifted material was added slowly and continually tamped around the tensiometer cup and tube so that uniform compaction could be achieved with a minimum number of large voids. Bentonite clay was used to seal the upper 10 cm of the hole to ensure that surface water did not travel downward along the tensiometer tube.

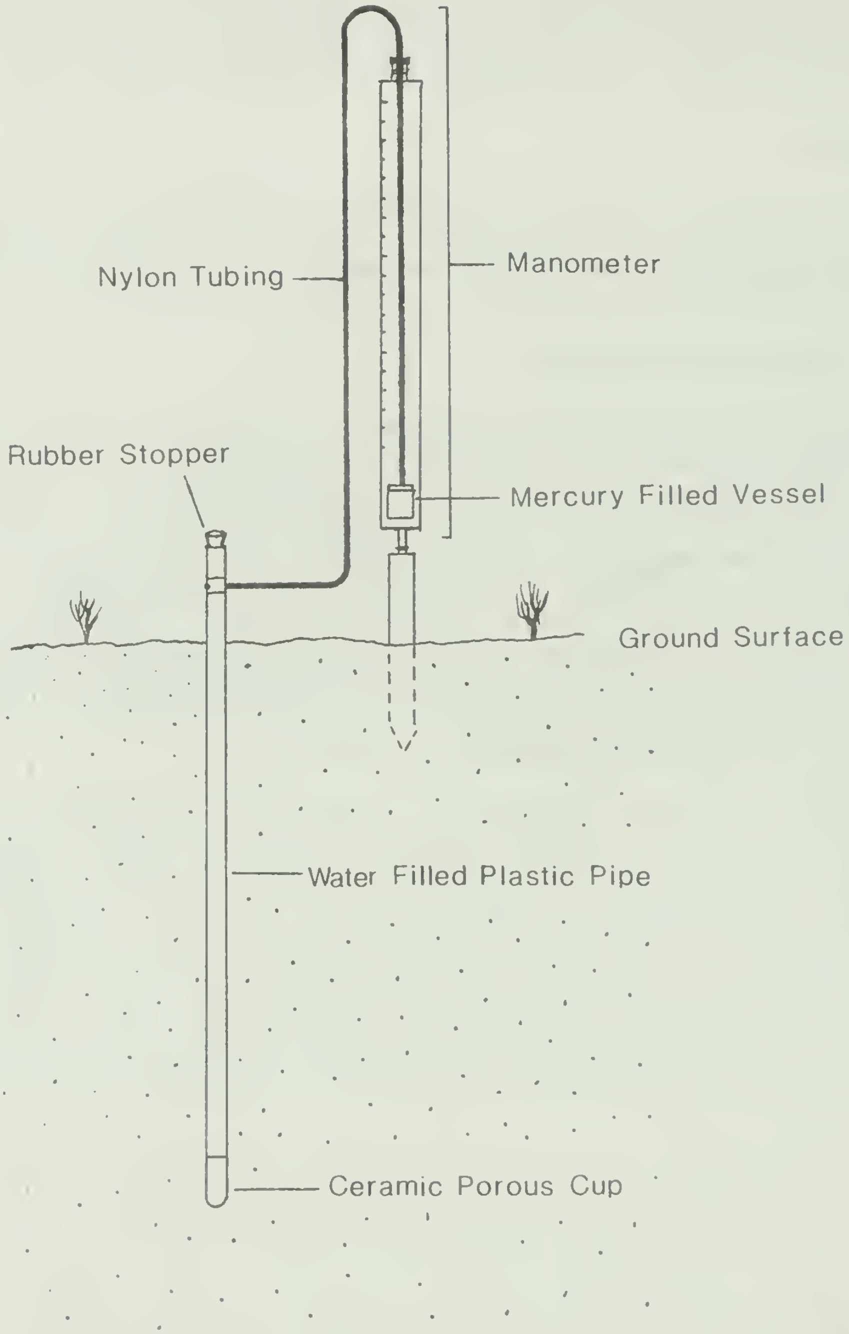


Figure 7. Schematic of tensiometer.

Soil moisture storage within the unsaturated zone was calculated from the soil tension data gathered from an array of 11 tensiometers, arranged in three nests (Fig. 8). Each nest consisted of a tensiometer at 1.5, 1.2, and 0.6 m below the surface, and two nests had an additional tensiometer at 0.3 m depth. These depths were chosen because the water table was observed to fluctuate between 1.2 and 2.5 m below the surface during the previous two winters (Sonnevil, 1987).

Soil tension fluctuations were monitored by manually recording mercury levels in the tensiometers (Fig. 8). The manometers can be read to ± 2 millibars (mb). During storm events, when soil tension changed rapidly, the tensiometers were read as often as once per hour. During dry periods, when soil tension changed slowly, readings were taken less frequently (typically every few days). The complete data is shown in Appendix C.

Because soil moisture contents were needed for the water budget, the soil capillary tension (suction) readings were converted to equivalent values of soil moisture. Different soils have different soil moisture retention characteristics, so it was necessary to relate soil moisture content to soil tension for the soil at the study site using the method outlined by Curtis and Trudgill (1974). As the tensiometer holes were augered, soil samples were taken at each depth to be monitored by the tensiometers. After field monitoring was completed, the tensiometers were removed from the field and inserted into the soil samples. The samples were then carefully wetted. When equilibrium was achieved, the sample was weighed. Using the wetted weights and an oven dry weight for the same sample, volumetric moisture (volume of water/total volume) and percent saturation (volume of water/volume of voids x 100%) values were calculated. This process was repeated over a range of different water contents so that tension versus percent saturation curves (referred to as soil moisture characteristic curves) could be developed for each soil sample depth.

Soil moisture tensiometers have a non-zero response time because water must move across the porous membrane of the instrument before it can register a pressure change (Klute and Gardner, 1962). Both soil hydraulic conductivity and the conductance of the tensiometer's porous cup can affect the response time. During the development of the soil moisture characteristic curves, lags observed in tensiometer response time were between 15 and 60 minutes. The average lag time for 23 measurements was 20 minutes.

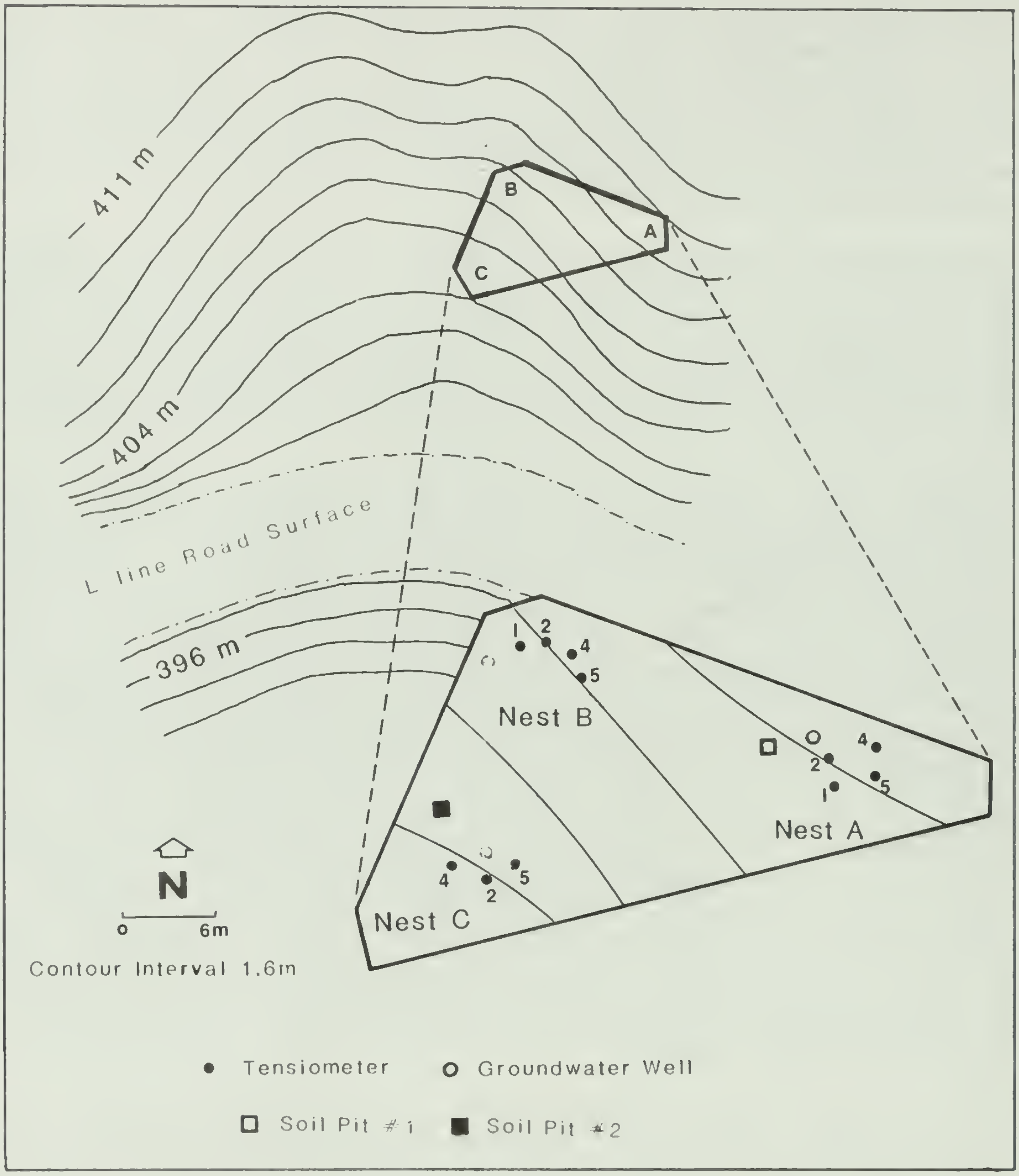


Figure 8. Locations of tensiometers, groundwater wells, and soil pits within hollow. Tensiometers A-1 and B-1 are 0.3 m deep, A-2, B-2, and C-2 are 0.6 m deep, A-4, B-4, and C-4 are 1.2 m deep, A-5, B-5, and C-5 are 1.5 m deep.

No attempt was made to measure the unsaturated hydraulic conductivity of this material because an abundance of these values for similar materials are available in the soil hydrology literature (Table 1). It was assumed that the large range of values (nine orders of magnitude) for other loams and silt loams in table 1 would bracket the silt loam under investigation. Any unsaturated hydraulic conductivity value needed in a calculation would come from within the range of the values in table 1.

TABLE 1

Values of unsaturated hydraulic conductivities for various soils.

Soil (reference)	Moisture Content (by volume)	Corresponding Hydraulic Cond. Range (cm/day)
Grenville silt loam (Staple, 1964)	0.25-0.50	.0004-12
Caribou silt loam (Topp, 1971)	0.29-0.44	.043-28
Idu silt loam (Green, et al., 1964)	0.20-0.50	.00014-24
Guelph loam (Jackson, et al., 1965)	0.25-0.50	.0072-43.2
Adelanto loam (Jackson, et al., 1965)	0.12-0.40	.0000014-1.4
Pachappa loam (Jackson, et al., 1965)	0.075-0.40	.0000014-7.2

B. Outflows

To monitor the rather complex boundary between the water table (saturated zone of positive pore pressure) and the unsaturated zone above, a groundwater well, approximately 2.5 meters deep was installed adjacent to each of the three tensiometer nests (Fig. 8). The holes, which were drilled with a power auger, were cased with 2 inch (5.1 cm) perforated PVC pipe and then backfilled with fine pea gravel to ensure good contact with the soil column.

Depth to the water table was measured in the perforated wells using an electronic sounder (Fig. 9) at the same times as tensiometer readings were made. Measurements made with the sounder are accurate to within $\pm$ 1 cm.

Figure 9. Measuring the depth to the water table in a groundwater well using an electronic sounder. Two tensiometers are shown in the foreground.

VII. RESULTS

A. Rainfall

During the monitoring period (12/2/87 to 3/19/88), 70 cm of rain fell in the area of the study site (Fig. 10a). This is close to the three year average of 72 cm at this site. The two significant storms that did occur, December 4-7, 1987 (Fig. 11a) and January 14-17, 1988 (Fig. 11c), accounted for 22 cm (almost one-third of the total rain during the study period). Maximum rainfall intensity recorded during the study period was 1 cm per hour. Rainfall data is tabulated in Appendix C. Antecedent precipitation (rain from 10/1/87 to 12/2/87) was 22 cm.

B. Soil Moisture Monitoring

As mentioned earlier, soil moisture characteristic curves (relating percent of soil saturation to soil moisture tension) were developed for each tensiometer depth (Fig. 12). Lateral variability of the soil mantle was investigated by digging a second pit to determine if soil samples could all be taken from a single soil pit and reasonably approximate the conditions at each tensiometer nest. The second soil pit (soil pit #2) was located near nest "A" (Fig. 8) and had a soil profile approximately 128 cm thick. This pit was not described in detail, but the profile was very similar to that of the soil in pit #1 (see Fig. 3). Because the two soil profiles were quite similar, the one sampling site was considered adequate to characterize the site. A second order polynomial regression of degree of saturation on tension was used to develop the relationship shown in figure 12.

In order to examine the saturated/unsaturated boundary and the position of the capillary fringe, degree of saturation (volume of water/volume of voids) was plotted against time for each depth in figure 10c-e (Note: figure is on following page).

Figure 10. Results of hydrologic monitoring from 12/2/87 to 3/19/88 (Julian days 335-80): a) cumulative rainfall, b) depth to water table measured in groundwater wells A, B, and C (records shown for these wells end early because they dried up in mid-March), c-e) degree soil saturation for tensiometer nests A, B, and C, respectively (see next page).

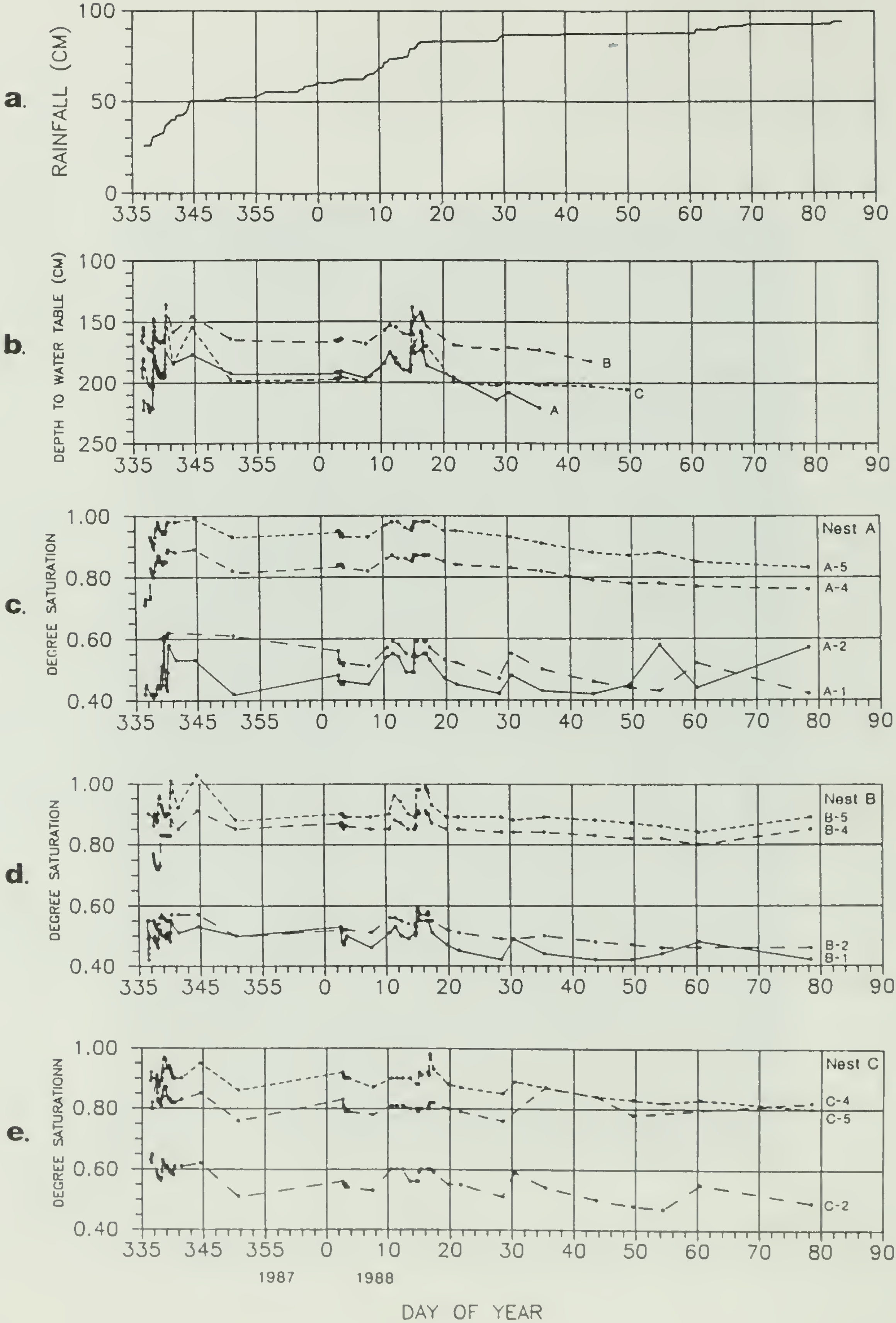


Figure 10. Caption on preceeding page.

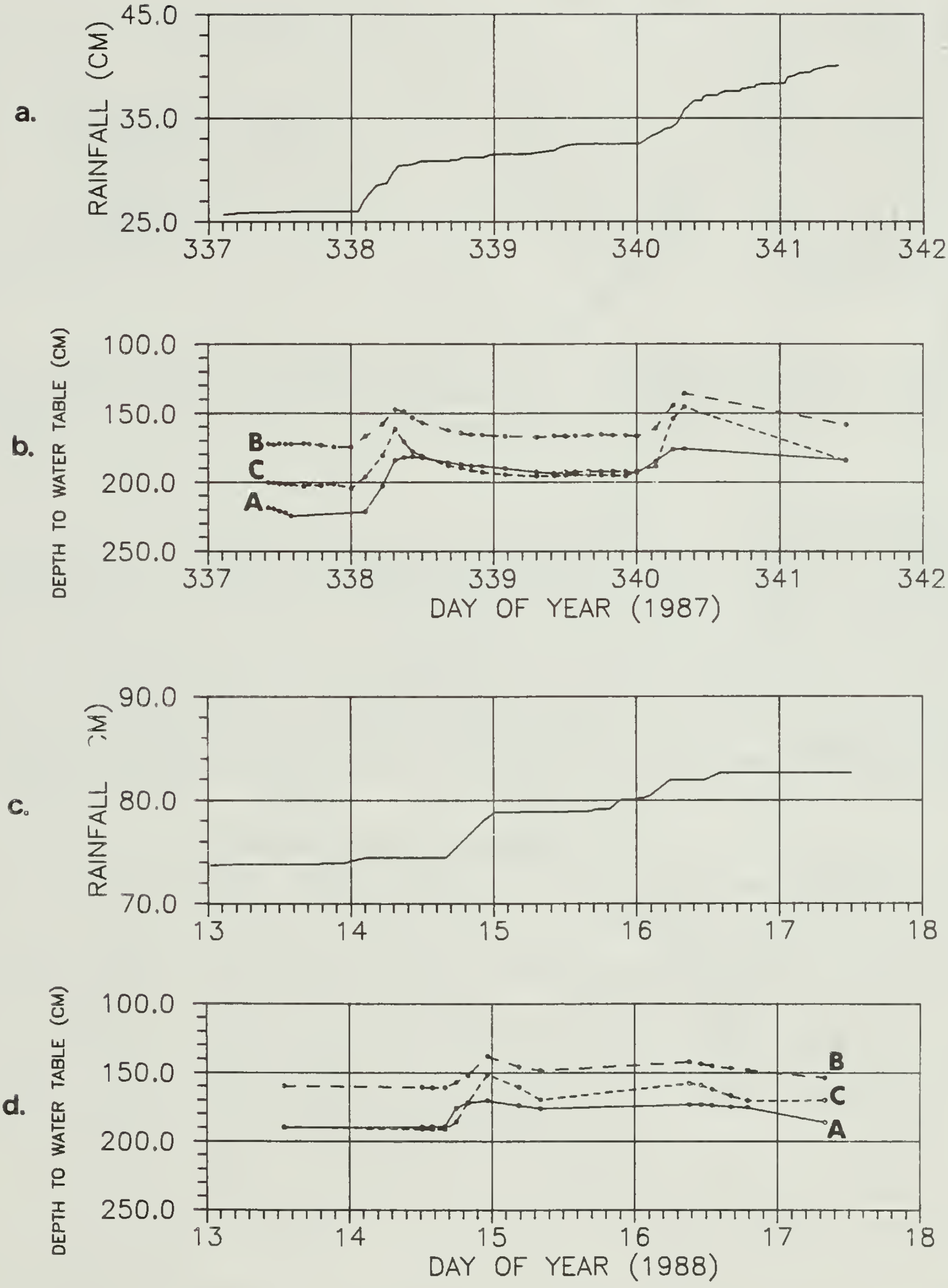
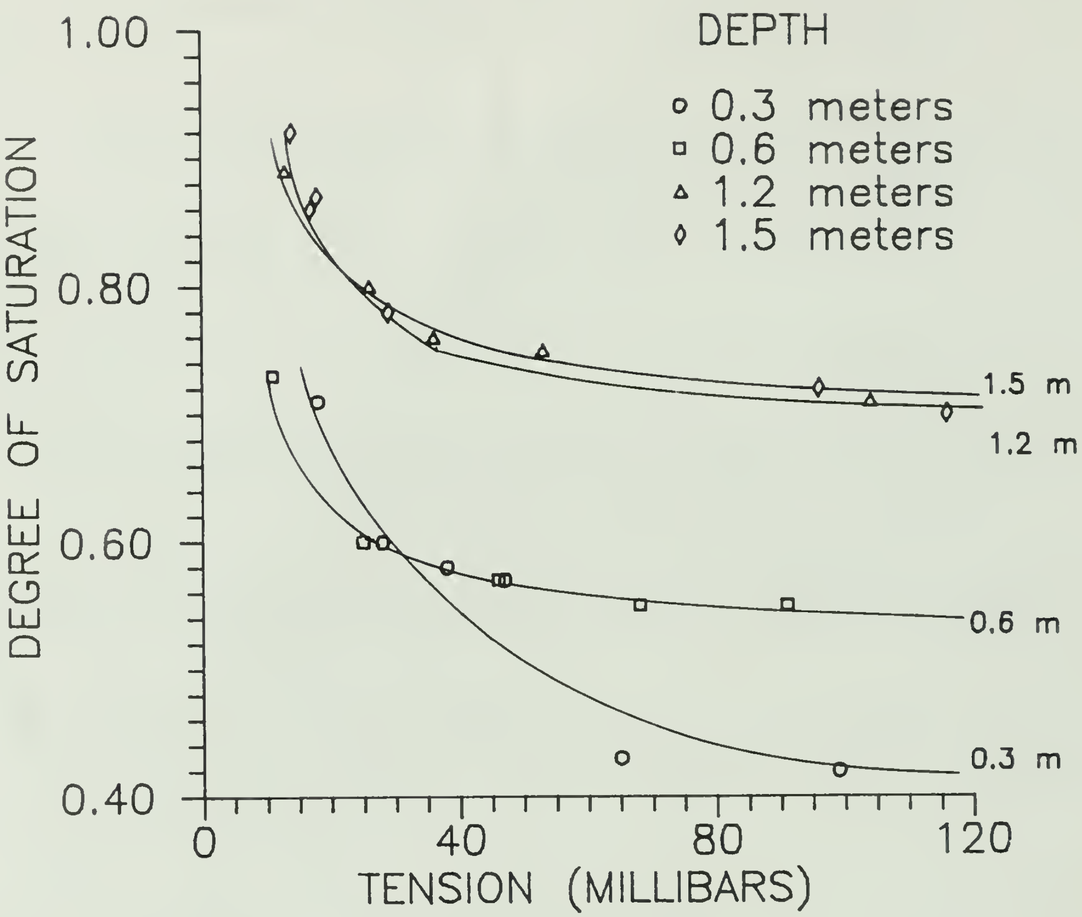


Figure 11. Rainfall and water table level for two storms during the monitoring period; December 4th storm (a and b), January 14th storm (c and d).



Depth	Equation	R^2
0.3 m	$DS = (4.7*10^{-5})T^2 - (9.0*10^{-3})T + 0.85$	0.89
0.6 m	$DS = (1.6*10^{-5})T^2 - (4.5*10^{-3})T + 0.75$	0.94
1.2 m	$DS = (3.6*10^{-5})T^2 - (6.1*10^{-3})T + 0.95$	0.94
1.5 m	$DS = (3.7*10^{-5})T^2 - (6.4*10^{-3})T + 0.97$	0.91

Figure 12. Soil moisture characteristic curves (relating soil moisture tension to percent soil saturation) for depths; 0.3, 0.6, 1.2, and 1.5 meters below the ground surface. Equations for the curves are shown with corresponding correlation coefficient (R^2) values.

Expanded plots in figure 13, which show soil moisture fluctuation with time, demonstrate that during the first significant storm, the tensiometers responded somewhat erratically. On two occasions, deeper tensiometers became wet before shallower ones of the same nest. Specifically, in figure 13b, tensiometer B-5 (1.5 m) shows wetting before B-4 (1.2 m). Similarly, A-4 (1.2 m) shows wetting before A-1 (0.3 m) (Fig. 13a). A-1 (0.3 m) and B-2 (0.6 m) show large fluctuations in soil moisture content while nearby tensiometers A-2 (0.6 m) and B-1 (0.3 m) were more steady (Figs. 13a and 13b).

During the later significant precipitation events of the monitoring period, the tensiometers responded more in unison than during the initial wetting (Fig. 14).

C. Water Table Monitoring

Water table fluctuations during the monitoring period, as measured in the three perforated wells, are shown in figure 10b. The water table response to rainfall events was very rapid. The water table responded to the January 14th storm within approximately 30 minutes of the onset of rainfall (Figs. 11b and 11d). This was the best storm to determine a response time of the water table since it was preceded by a dry period, and the time the rain first entered the soil column is known.

Relatively small amounts of rainfall appear to cause large rises in the water table (Fig. 11). In the December 4th storm, 4.5 cm of rain caused a 40 cm rise in well "A", a 43 cm rise in "B", and a 27 cm rise in "C" (Fig. 11b). For the December 4th storm water table levels peaked approximately 4 hours after the onset of rainfall. In the January 14th storm (Fig. 11d), 4.8 cm of rain caused a water table rise of 19 cm in well "A", 23 cm rise in "B", and a 40 cm rise in "C". For the January 14th storm water table levels peaked approximately 7 hours after the onset of rainfall.

The average specific yield, Sy, of the soil column (Appendix A) can be used to determine the expected water table rise, Wr, if the amount of rainfall, Rd, entering the system is known, by the equation:

$$Wr = \frac{Rd}{Sy}$$

This calculation assumes that: 1) the soil column is at field capacity at the onset of rainfall, 2) all the water reaches

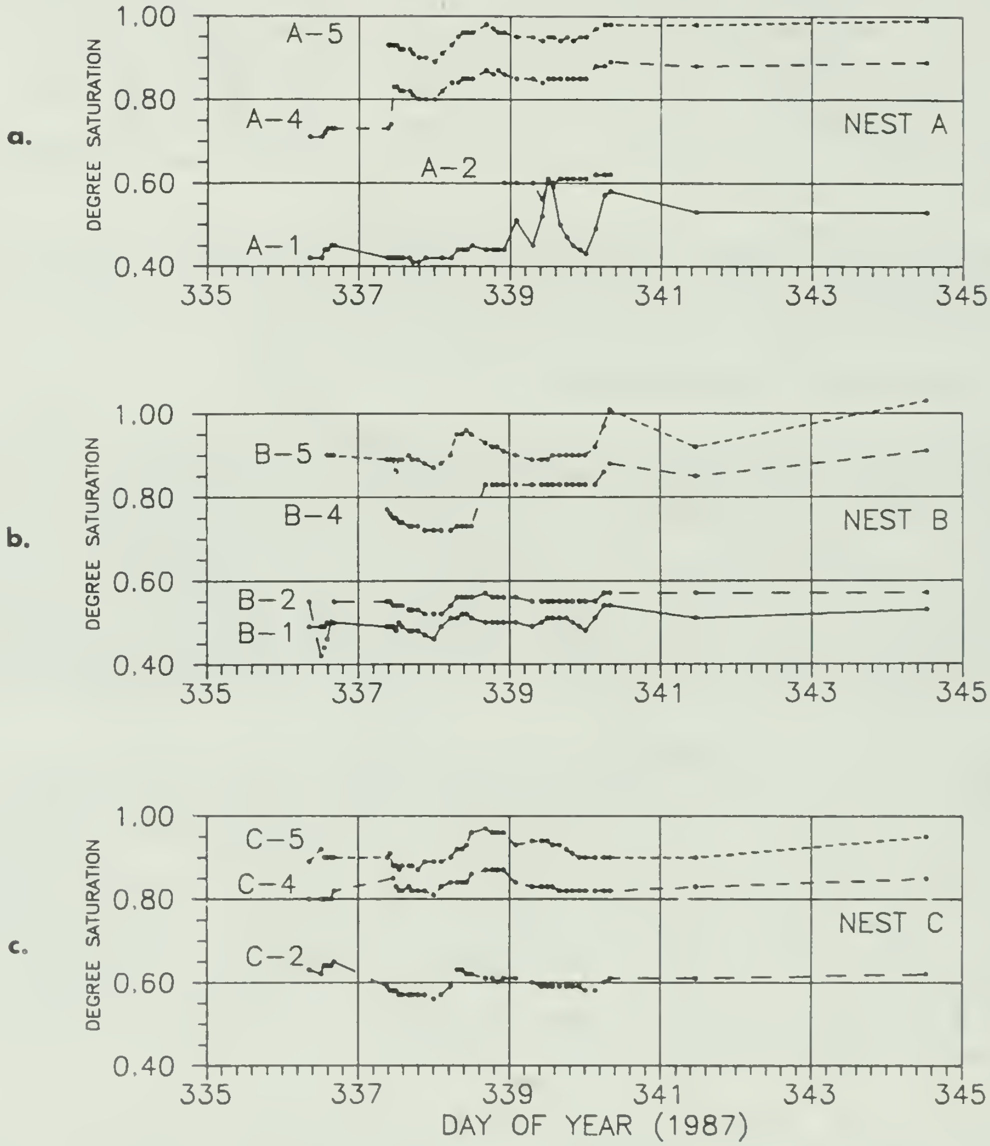


Figure 13. Soil moisture (degree saturation = volume water / volume voids) fluctuations in time for the December 4th storm as reflected in tensiometer nests A (a), B (b), and C (c). Much of the "A-2" data was lost because of tensiometer malfunction.

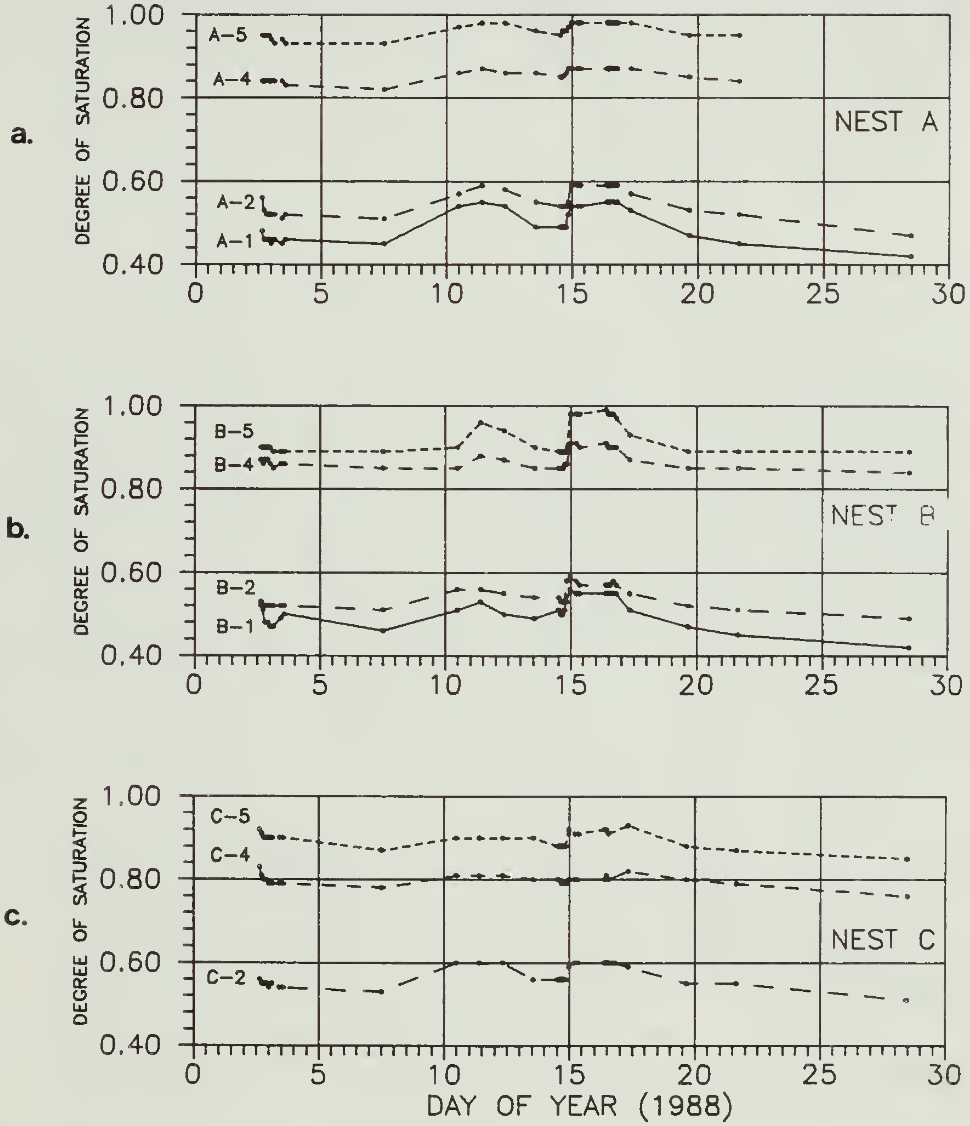


Figure 14. Soil moisture (degree saturation = volume water / volume voids) flucuations in time for the January 14th storm as reflected in tensiometer nest A, B, and C. Note the uniformity of the fluctuations.

the water table, 3) significant lateral unsaturated flow does not occur, and 4) no groundwater outflow occurs. Note that violation of any of these assumptions would decrease the amount of water table rise. Using this equation, 4.5 cm of rain should cause a water rise of 17.3 cm, and 4.8 cm of rain a rise of 18.5 cm. The observed water table rises, which are larger than expected, suggest that the soil moisture is above field capacity.

VIII. DISCUSSION

There are three primary ways in which water may traverse the unsaturated zone and reach the water table: 1) event water (i.e., water from a single precipitation event) may infiltrate the ground surface and travel through the soil matrix until it reaches the water table (Darcian matrix flow, Fig. 15a), 2) event water may, for the most part, bypass the soil pores and reach the water table through macropores or along root channels (macropore flow, Fig. 15b), or 3) may exhibit another type of matrix flow where event water displaces pre-event water in a wave-like manner (translatory flow, Fig. 15c).

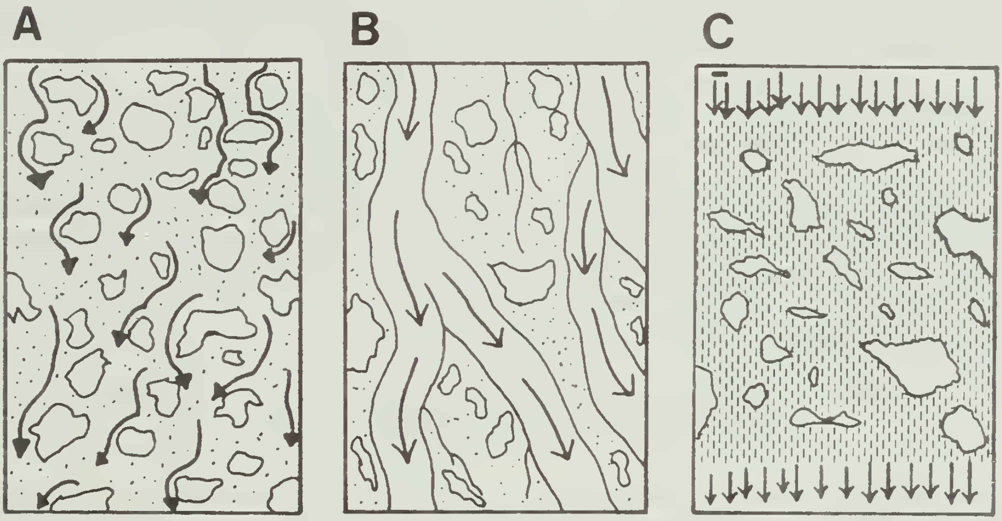


Figure 15. Three primary ways water can traverse the saturated zone. A) Matrix flow; water travels through the soil pores. B) Macropore flow; water travels through macropores, pipes, and along root channels. C) Translatory flow; event water entering the soil mantle at the top displaces water stored in the soil pores, forcing water out at the bottom. The textured area represents a soil mantle at field capacity.

A. Darcian Matrix Flow

The importance of this mechanism of transport can be examined by determining the average linear velocity of water moving downward through the soil column and comparing it to the response time of the water table to rainfall. If the time it

takes for the water table to respond to rainfall is consistent with the calculated average linear velocity then matrix flow is likely be the dominant mechanism of transport. The equation for average linear velocity, v, is (Freeze and Cherry, 1979):

$$v = \frac{k}{n}\frac{dh}{dl}$$

where k = hydraulic conductivity of the soil, n = porosity, and dh/dl = head gradient.

The purpose of this calculation is to determine whether or not matrix flow can be rapid enough to account for the observed water table rises. Therefore, values for the variables were chosen which would maximize the result.

A hydraulic conductivity (k) of 43.2 cm/day (see table 1) was used to calculate velocity. The average porosity (n) of the soil is 0.57 (Appendix A). The average total hydraulic head difference (dh), 73 cm, is calculated from the tensiometer readings just prior to the January 14th storm (Appendix B). The distance between the porous cups of the tensiometers where the head values were measured (dl) was 120 cm. The maximum average linear velocity, then, is:

$$v = \frac{(43.2\ \text{cm/day})}{(.57)}\ \frac{(73\ \text{cm})}{(120\ \text{cm})} = 46.1\ \text{cm/day}$$

At this velocity it would take the center of mass of infiltrated rainfall over 4 days to reach the average position of the water table (approximately 180 cm below the surface). The groundwater data shows water table response in as little as 30 minutes. If the values for the loams and silt loams in table 1 are applicable to the silt loam in the hollow, matrix flow could not account for the rapid water table rises.

B. Macropore Flow

Soil moisture data from the December 4th storm suggests that flow occurs in macropores and along roots. Figures 13a and 13b show that, in some cases, deeper soil showed wetting before shallower soil. If uniform infiltration through the soil matrix occurred, shallower soil should consistently show wetting before deeper soil. The likely explanation for the locally inverted wetting front is that rainfall bypassed the upper level of the soil matrix via macropores, and wetted the lower level first.

The erratic response of the tensiometers during the December 4th storm (Fig. 13) further supports the mechanism of macropore flow. An uneven wetting of the soil should be expected when macropore flow is the dominant transport mechanism because soil matrix wetting occurs downward from the ground surface, outward from the macropores and roots (which randomly criss-cross the soil mass), and upward from the water table. This process is reflected in the response of tensiometer nest "B" (Fig. 13b) to the December 4th storm, where wetting occurred downward from the ground surface and upward from the water table (B-1 and B-5 show wetting before B-2 and B-4).

It is important to note that this is not necessarily always the case. A macropore could be located very near the porous cup of any of the tensiometers and cause a rapid response to infiltration. The important observation, that is difficult to explain by any other mechanism, is the inverted wetting of the soil column and the erratic response of the tensiometers.

It might be argued that large voids in the backfilled material in the tensiometer holes were breaking down during the progressive wetting of the soil as the season went along and that this may cause the seemingly erratic initial tensiometer response and more uniform response later. Because every effort was made to ensure a uniform backfill free of large voids, the observed responses likely reflect true moisture variations in the surrounding, undisturbed soil.

Macropores and roots, which are abundant in the upper one meter of the soil column, increase the openness and infiltration capacity of the soil (Chamberlin, 1972). Since overland flow was never observed, the infiltration capacity of the study site was probably never exceeded.

C. Translatory Flow

While it appears that macropore flow was the dominant transport mechanism during the December 4th storm, evidence suggests that translatory flow dominated moisture flow through the unsaturated zone after that first significant storm. After initial wetting in the December 4th storm the responses of the tensiometers were much more uniform (see Fig. 14). Their nearly simultaneous response suggests that they were somehow hydraulically coupled, not randomly wetted. Since the tensiometers responded uniformly, the entire soil mass must have been involved in moisture transport. Darcian type matrix flow (see page 19) cannot be the dominant transport mechanism because it is far too slow to account for the rapid water

table responses. Translatory flow can rapidly deliver water to the water table (Hewlett and Hibbert, 1967). By this mechanism, new water entering the top of the soil column displaces stored water. The new water becomes stored water and causes a pulse or wave of water to move rapidly down the soil column.

Horton and Hawkins (1964) provide experimental evidence for translatory flow. They drained a column of soil to field capacity in the lab and then added one inch of tritium-tagged water to the top. The first outflow of water contained no tritium. Each day they added one inch of plain water to the top of the column. Each day they analyzed the effluent for tritium. The tritium tagged inch of water moved slowly down the column, pushing ahead of it 87% of the water that was stored in the soil before the tritium was added. They concluded that each rain tends to displace most of the water stored in the soil column ahead of it.

The velocity at which the hypothesized translatory pulse moves down the soil column can be calculated by dividing the distance travelled to the water table (180 cm), by the time it takes the water table to rise in response to rainfall (30 minutes). The translatory wave velocity for the January 14th storm is approximately 6 cm/min. If the average lag time of the tensiometers (20 minutes; page 21) is subtracted from the water table response time (30 minutes), flow velocity through the unsaturated zone could be as fast as 18 cm/min. I found no values in the literature for the velocity of a translatory wave through a soil mantle. Gillham (1984) did report a water table response of 15 seconds in a field sand.

D. Flow Model for the Unsaturated Zone

The results support a model suggested by DeVries and Chow (1978): at the beginning of the rainfall season, when soil moisture is relatively low and hydraulic conductivity is consequently low, resistance to downward flow in macropores and along roots is smaller than that in the soil matrix. For this reason, macropore flow dominates transport in the unsaturated zone during the first significant storm of the season.

As wetting occurs downward from the ground surface, outward from the macropores and roots, and upward from the water table, the resistance to flow in the soil matrix decreases. Once the entire soil matrix is wetted, there is a reduction in the difference between the resistance to flow in the macropores and that in the soil matrix. Although DeVries and

Chow (1978) do not discuss translatory flow, the evidence from this investigation suggests that it becomes the dominant transport mechanism after the soil mass is wetted.

Since the manner of flow through the unsaturated zone of the colluvial hollow in this investigation is very similar to that discovered by DeVries and Chow (1978) in a straight (non-convex) sloping forested soil, bedrock geometry apparently has little effect on flow through the unsaturated zone.

E. Water Table Rises

Rainfall events caused disproportionately large water table rises relative to soil specific yield several times during the monitoring period (see Figs. 11b and 11d). The large water table rises can be explained by the presence of a thick capillary fringe, where water is stored above field capacity in the soil pores, but below positive pressure saturation (Fig. 16). Only a small amount of water is required to convert the capillary zone of tension saturation or near-saturation to a zone of positive pressure saturation or groundwater. When this occurs the water table rises quickly.

The evidence suggests that the mechanism by which water is transported to the capillary fringe is not important to water table rises because large rises occur both when macropore flow is dominant as well as when translatory flow is dominant. The zone immediately above the water table can draw water up from the positive pressure saturated zone and hold it in the soil pores by capillary forces. When either a translatory flow pulse or water from a macropore encounters the near-saturated conditions, rapid water table rise results.

Since rates of rainfall changed rapidly with time, steady state conditions were never observed in this hydrologic system. It is therefore difficult to make simple calculations regarding the effect of a single storm on the water table. Well "C", located in the hollow axis, consistently showed greater water table rises than the other wells (see Fig. 11b and 11d) and suggests that convergent groundwater flow is probably occurring. The constantly changing groundwater hydraulic gradients further complicate the task of simple calculation.

A transient groundwater flow model would be required to account for the changing rainfall rates, groundwater gradients, unsaturated hydraulic conductivities, and soil moisture contents. However, even the existing sophisticated

mathematical models that couple unsaturated and saturated flow cannot yet adequately describe macropore flow (Beven and Germann, 1982).

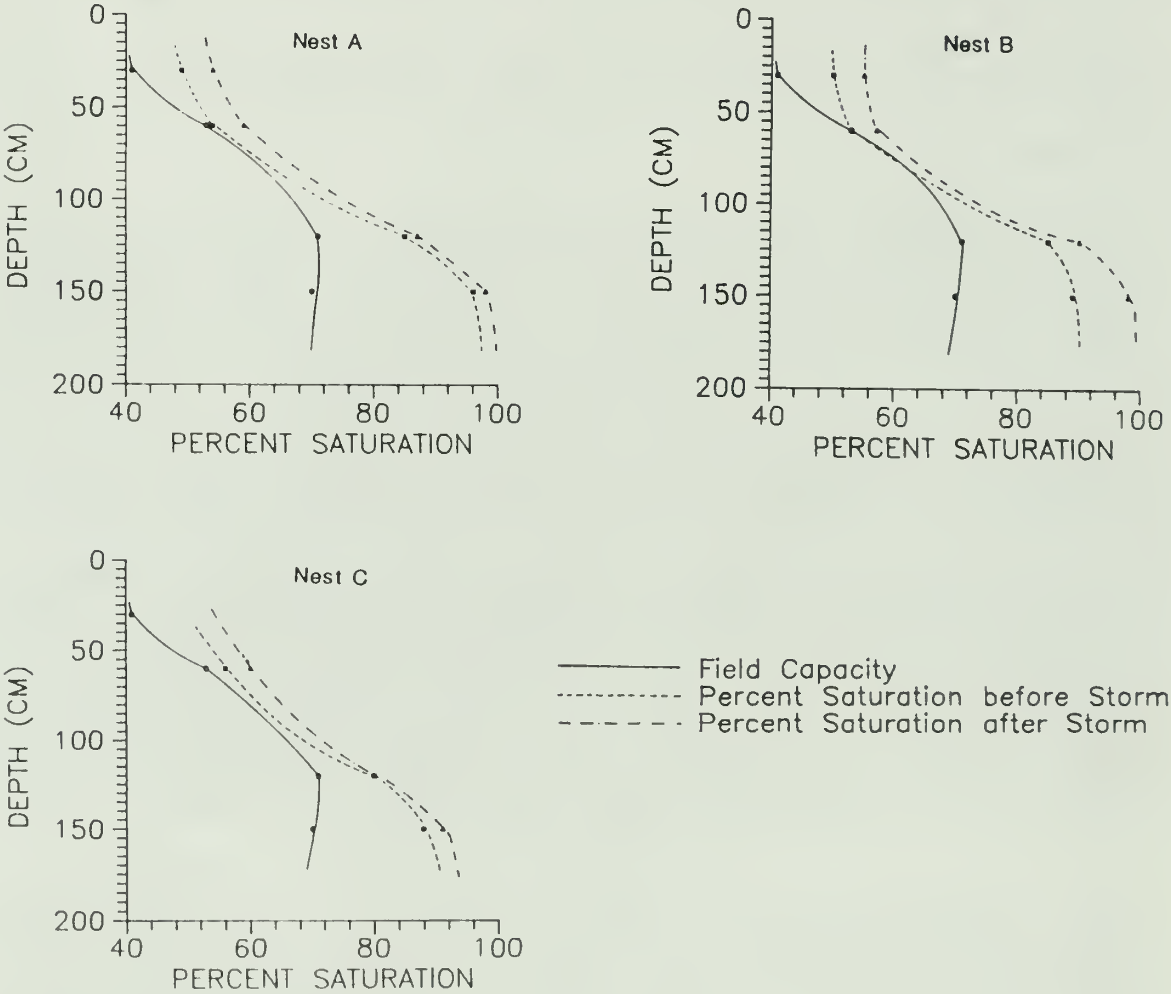


Figure 16. Soil moisture profiles for the January 14th storm as reflected in the three tensiometer nests. Note the large discrepancy between field capacity and actual moisture content before the storm.

The accuracy of the soil moisture data can be estimated by comparing moisture contents of the soil before and after a storm. The difference between the amount of rainfall entering the soil column and the increased amount of water held in the in soil pores can be used to predict the water table rise.

A storm was chosen that had a distinct burst of rain with short dry periods before and after so that the amount of rainfall entering the system was known and the tensiometers would have a chance to equilibrate somewhat before and after the storm. The storm that most nearly met these criteria was the January 14 event in which 4.8 cm of rain fell in 8 hours (Fig. 16). A single tensiometer nest (nest "B") and corresponding groundwater well (Fig. 17) was chosen for the example calculation. The results for all three nests are reported at the end of the discussion.

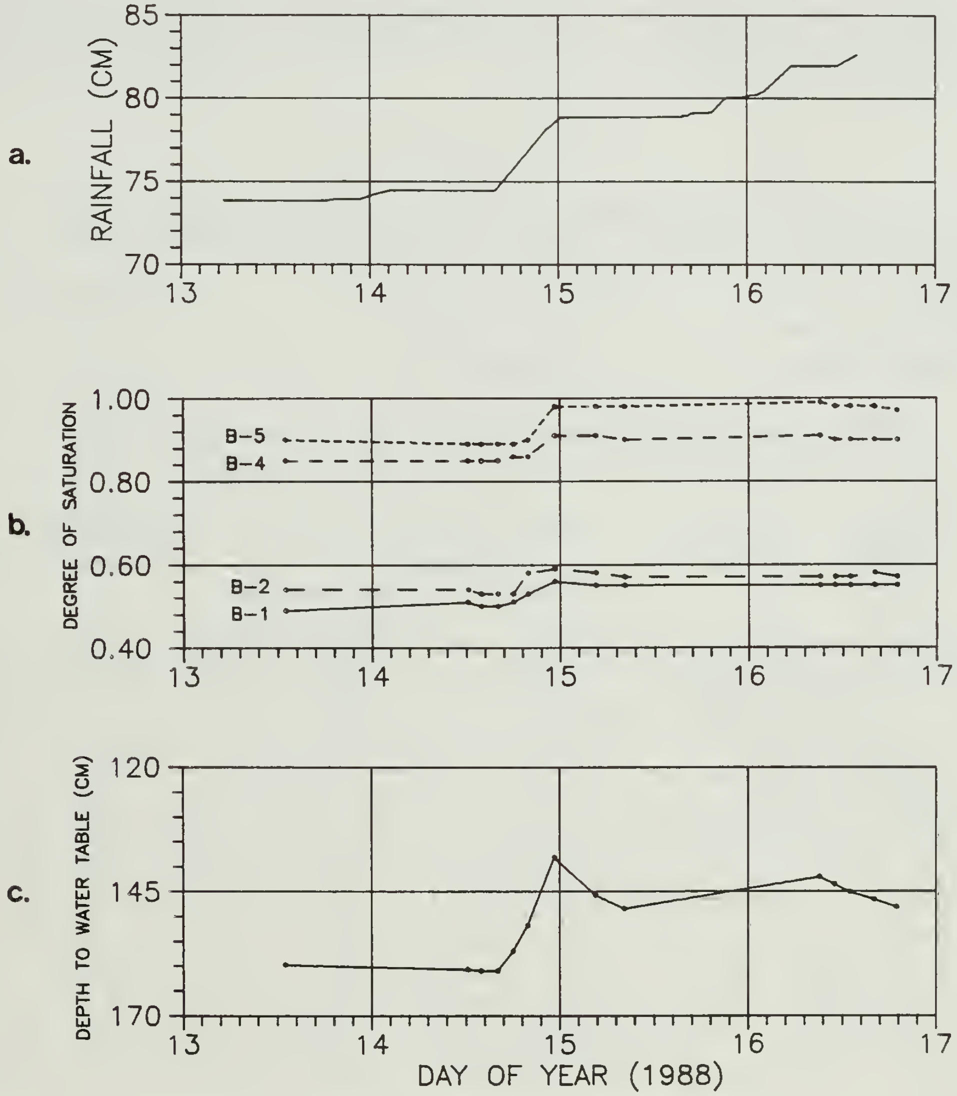


Figure 17. January 14th storm; a) rainfall, b) percent saturation, and c) depth to water table.

The soil column was divided into four approximately 0.5 m long sections (Table 2), roughly centered on each of the four tensiometers. The bottom section of the sample for this calculation is only 3 cm in length because the water table came to this depth. An assumption was made that the moisture value reflected in each tensiometer approximated that of the entire associated soil section. The change in degree of saturation of each soil section represents part of the total 4.8 cm of rain which is effectively being held by that section (Table 2). While event water may not actually traverse the entire soil column, there will be a net change in degree saturation (dsat) in each soil section. Degree saturation change can be converted to depth (inches) of rain, d, retained by that section by the equation:

$$d = (dsat)(l)(n)$$

where "l" equals the height of the section (cm), and "n" is its porosity. Table 2 shows this calculation for each section.

TABLE 2

Soil Moisture properties by vertical section for the storm of January 14, 1988.

Position in Soil Profile (cm)	Thickness (cm)	Porosity (n)	Degree of Saturation (dsat) Pre-storm	Post-storm	Increase in dsat	Water Content (cm)
0-45	45	0.68	0.50	0.55	0.05	1.53
45-90	45	0.64	0.53	0.57	0.04	1.15
90-135	45	0.52	0.85	0.90	0.05	1.17
135-138	3	0.44	0.89	0.98	0.09	0.12

By the time the water surge reaches the last section, only 0.83 cm of water is still available [4.8 cm - (1.53 + 1.15 + 1.17 + 0.12)cm]. The expected water table rise, "l", caused by this 0.83 cm can be calculated by rearranging the previous equation:

$$l = d/[(dsat)(n)]$$

which yields a value of 17 cm. The actual water table rise was 23 cm, which is in fair agreement considering the assumptions made. The wave-like pulse delivers only 0.83 cm of water to the area of the water table but causes a 23 cm rise, which supports the hypothesis of a thick capillary fringe.

Table 3 shows the results for all three groundwater wells. The large overprediction of the water table rise in well A may be the result of its side slope position in the swale. Perhaps groundwater flow directed toward the axis of the hollow will not allow elevated water table levels and the development of high groundwater gradients during this magnitude of storm.

TABLE 3

Predicted and actual water table rises.

Groundwater well	Predicted water table rise (cm)	Actual maximum measured water rise (cm)
A	60	19
B	17	23
C	42	40

Rapid water table rises can induce groundwater hydraulic gradients directed toward the toe of a slope causing immediate outflow to a stream (Abdul and Gillham, 1984; Pearce, et al., 1986). If the observed water table rises in this investigation produce immediate outflow of groundwater to a stream, then the only cause for a lag between rainfall and streamflow response is the time moisture takes to travel through the unsaturated zone. For this reason, the condition of the unsaturated zone, including the forest floor, is an important factor in drainage basin response to storm events.

IX. SUGGESTIONS FOR FUTURE RESEARCH

The mechanism of translatory flow in a soil mantle is poorly understood (Pearce, et al.; 1986). This investigation strongly suggests that translatory flow does occur, but does not provide detailed observations on the mechanism itself. Laboratory research studies on soil columns could determine conditions and soil properties that affect the rate of translatory flow.

Mathematical modeling of the translatory pulse through the soil column would be an important step in understanding the physical basis of the phenomenon. Modeling moisture flow through a forest soil, where macropore and translatory flow both occur, is a process that may challenge mathematical hydrologists for some time.

X. CONCLUSIONS

Macropores and roots are very abundant in the upper one meter of the soil mantle. These, combined with a layer of forest liter, help provide a high infiltration capacity, which was never observed to be exceeded during the moderate winter of 1987-88.

During the first significant storm of the season, the relatively low soil moisture content of the soil caused resistance to flow in macropores to be less than that through the soil matrix. Thus, macropore flow was likely the dominant transport mechanism in the unsaturated zone. In subsequent storms, translatory flow was likely the dominant transport mechanism because 1) the entire soil mass showed wetting and 2) the water table rises in response to rainfall were too rapid for matrix flow. The translatory wave velocity was calculated to be between 6 and 18 cm/min. A capillary fringe, where water is stored in the soil pores under capillary tension and above field capacity, accounts for the seemingly disproportionate water table rises.

There is no evidence to suggest that the hydrology of the unsaturated zone of a colluvial hollow is different than that of any other forest soil. If flow to streams occurs almost immediately upon significant water table rise, then only the time it takes for moisture to flow through the unsaturated zone can cause a significant lag time between rainfall and streamflow response. The condition of the unsaturated zone can have a major impact on the stormflow response time of a forested watershed.

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APPENDIX A

Porosity and Specific Yield

Porosity, n, is defined as volume of the voids divided by total volume. Porosity calculations for the soil samples are summarized below:

Depth of Sample (meters)	Total Volume (cm^3)	Volume of Voids (cm^3)	Porosity (dimensionless)
0.3	763	518	0.68
0.6	763	492	0.64
1.2	763	393	0.52
1.5	763	335	0.44

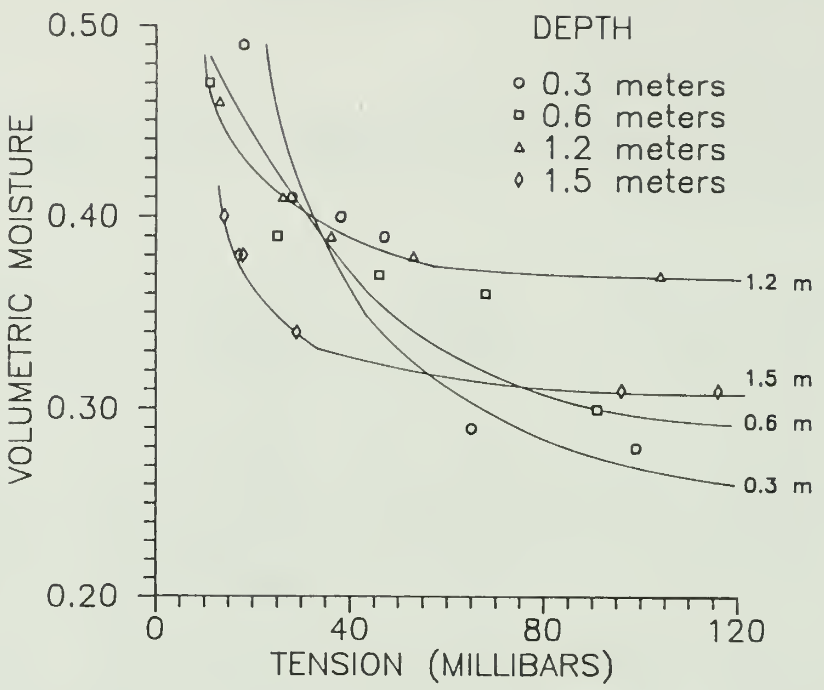
To determine the average porosity of the soil column:

$$\frac{(0.68 + 0.64 + 0.52 + 0.44)}{4} = 0.57$$

Specific yield is defined as the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table (Freeze and Cherry, 1979). Specific yield, Sy, can be approximated by the equation:

$$Sy = n - fc$$

where n = the porosity and fc = the field capacity of the soil. By American convention, field capacity is equal to the volumetric moisture content of the soil at 100 mbars of tension (Curtis and Trudgill, 1974). The following page shows moisture characteristic curves for each sampled depth, which were developed during the tensiometer calibration. Soil moisture values that correspond to 100 mbars of tension are also tabulated.



Depth of Sample (m)	Porosity	Field Capacity (100 mbars)	Specific Yield
0.3	0.68	0.26	0.42
0.6	0.64	0.31	0.33
1.2	0.52	0.37	0.15
1.5	0.44	0.32	0.12

The average specific yield, Sy, of the soil column is:

$$\frac{(0.42 + 0.33 + 0.15 + 0.12)}{4} = 0.26$$

APPENDIX B

Head Difference

To determine the hydraulic head difference for moisture in the unsaturated zone before the January 14th storm, use the equation:

$$dh = h_1 - h_2$$

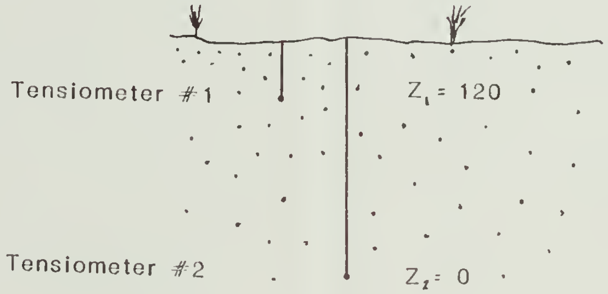
where, $h_1 = Z_1 + \Upsilon_1$

$h_2 = Z_2 + \Upsilon_2$

and, Z = position head

Υ = pressure head

Diagrammatically,



The Υ_1 and Υ_2 readings from the tensiometers on 14.58 (Jan 14th) were -57 mbars and -2 mbars, respectively from nest "A", and -53 mbars and -13 mbars from nest "B". At this scale mbars approximately equal cm of water. Therefore,

$$dh \text{ (nest A)} = [120 \text{ cm} + (-57 \text{ cm})] - [0 + (-2 \text{ cm})] = 65 \text{ cm}$$

$$dh \text{ (nest B)} = [120 \text{ cm} + (-53 \text{ cm})] - [0 + (-13 \text{ cm})] = 80 \text{ cm}$$

$$\text{The average } dh = \frac{65 \text{ cm} + 80 \text{ cm}}{2} = 73 \text{ cm}$$

APPENDIX C

Raw Data

DATE	TIME	JULIAN DATE	WELL WA (FT BELOW SURFACE)	TENSIOMETERS (MBARS) A1	A2	A4	A5	WELL WB (FT. BELOW SURFACE)	TENSIOMETERS (MBARS) B1	B2	B4	B5	WELL WC (FT BELOW SURFACE)	TENSIOMETERS (MBARS) C2	C4	C5
12/2/87	8 23	336.35	DRY	86	NA	154	204	6 47	56	NA	NA	NA	7 13	30	226	242
12/2/87	12 15	336 51	DRY	83	NA	153	186	6 53	55	132	NA	NA	7 37	32	226	237
12/2/87	13 15	336 55	DRY	74	NA	146	179	6 34	55	110	NA	NA	7 14	27	225	240
12/2/87	14 15	336 59	DRY	71	NA	144	173	6 19	54	93	NA	171	6 93	26	225	240
12/2/87	15 15	336.64	8 17	69	NA	144	173	6 11	54	73	NA	170	6.86	26	225	239
12/2/87	16 15	336 68	7 92	70	NA	142	170	6 17	53	53	NA	170	6 89	25	222	239
12/3/87	9 00	337 38	8 02	86	NA	142	121	6 69	57	54	278	173	7.52	42	206	239
12/3/87	10 00	337.42	8 04	88	NA	140	121	6 70	57	54	275	172	7.52	43	205	238
12/3/87	11 00	337 46	8 06	88	NA	112	121	6 72	57	56	271	172	7 53	44	214	243
12/3/87	12.00	337 50	8 11	90	NA	113	121	6.69	58	57	269	178	7 55	45	219	243
12/3/87	13 00	337 54	8.15	91	NA	114	122	6 70	54	58	268	172	7.55	46	220	245
12/3/87	14 00	337 58	8 23	91	NA	115	123	6 70	57	58	267	172	7.56	46	220	243
12/3/87	16 00	337 67	0.00	93	NA	116	122	6.69	58	60	263	171	7 61	46	218	243
12/3/87	17 00	337 71	0.00	95	NA	118	124	6.70	59	60	263	172	7.56	46	221	244
12/3/87	19 00	337 79	0.00	97	NA	119	125	6.73	60	60	261	172	7.59	47	221	246
12/3/87	21 00	337.88	0.00	99	NA	119	126	6.77	62	62	258	174	7 61	48	221	242
12/4/87	0 01	338 00	0 00	108	NA	121	128	6 77	64	62	258	176	7 66	51	223	242
12/4/87	2 30	338 10	8 13	100	NA	116	124	6.52	57	62	257	174	7.38	48	218	241
12/4/87	5 10	338 22	7 52	88	NA	111	120	6 23	51	55	255	170	6.88	42	217	240
12/4/87	7 30	338 31	6 91	75	NA	110	118	5.88	50	49	201	162	6 25	28	216	236
12/4/87	8 50	338 37	6.84	74	NA	108	116	5.93	49	49	200	162	6 55	29	216	236
12/4/87	10 15	338 43	6 82	72	NA	108	116	6 08	49	49	200	160	6.78	32	216	235
12/4/87	12 05	338 50	6.85	70	NA	108	116	6 20	50	49	200	162	6.89	31	212	230
12/4/87	16 15	338 68	6 96	71	NA	105	113	6.38	53	47	171	165	7 12	36	210	228
12/4/87	18 30	338.77	7.00	71	NA	106	114	6 44	53	49	172	167	7 17	36	210	230
12/4/87	20 15	338.84	7.04	71	NA	105	115	6 48	53	50	172	168	7.23	37	211	229
12/4/87	22 00	338.92	7 05	71	37	106	115	6 49	54	49	171	169	7 27	36	211	229
12/5/87	2 00	339 08	7 10	50	38	108	118	6 51	54	50	172	170	7 33	35	216	234
12/5/87	7 15	339 30	7.19	70	38	108	117	6 54	56	52	172	172	7.37	39	218	233
12/5/87	10 00	339.42	7 22	48	49	110	119	6 51	54	52	172	172	7.36	42	219	233
12/5/87	12 00	339 50	7.19	31	39	109	118	6.52	52	52	172	172	7.35	41	219	233
12/5/87	13 40	339 57	7.19	35	39	109	118	6 51	51	51	172	171	7.33	40	219	234
12/5/87	15 50	339 66	7.17	54	36	109	119	6.50	51	52	172	170	7.34	41	220	235
12/5/87	18 00	339 75	7 18	63	34	108	118	6.48	52	52	172	170	7 35	40	221	237
12/5/87	20 00	339 83	7 17	67	34	108	119	6.50	54	52	172	170	7 35	41	222	238
12/5/87	22 00	339.92	7 18	73	34	108	118	6.50	55	54	172	170	7 37	42	221	240
12/6/87	0 01	340 00	7 21	77	34	108	118	6.52	58	54	171	171	7 25	43	222	240
12/6/87	3 00	340 13	6 94	57	33	103	114	6 33	52	53	171	167	7 14	43	222	240
12/6/87	6 00	340 25	6.65	38	33	102	113	5.79	44	46	165	159	6 01	38	222	240
12/6/87	8 00	340 33	6.64	36	31	101	112	5.50	45	46	162	153	5 72	35	222	240
12/7/87	11 00	341 46	6 90	46	NA	103	113	6 25	50	46	168	168	7.00	34	218	239
12/10/87	12 30	344 52	6.68	47	NA	101	111	5 82	47	45	156	150	6.02	33	214	231
12/16/87	15.30	350 65	7 18	87	36	114	121	6 43	60	70	167	174	7 43	68	238	248
1/2/88	15 00	2.63	7 17	60	50	110	118	6 49	47	63	164	170	7.41	51	218	237
1/2/88	17 00	2 71	7 17	64	62	110	118	6.49	52	63	165	171	7 41	54	224	238
1/2/88	19 00	2 79	7 17	64	64	110	118	6 49	58	63	164	171	7 41	55	226	239
1/2/88	22 00	2 92	7 17	64	64	110	118	6 49	58	63	164	171	7 41	55	226	239
1/3/88	0 01	3 00	7 16	67	67	111	119	6 48	63	65	165	171	7 42	56	228	239
1/3/88	3 00	3 13	7 17	66	67	111	120	6 47	62	65	167	173	7 39	55	229	240
1/3/88	10 00	3 42	7 17	67	68	111	119	6 46	55	65	166	173	7 38	57	229	240
1/3/88	13 30	3 56	7 13	65	67	112	120	6 43	54	65	166	173	7 37	57	229	239
1/7/88	12 00	7 50	7 32	69	69	114	121	6 57	64	67	167	173	7 50	62	232	245
1/10/88	11 30	10 48	6 91	45	46	106	114	6 20	50	49	167	170	6.99	38	223	239
1/11/88	9 40	11 40	6 61	43	42	104	112	6 06	46	49	161	161	6.70	39	223	239
1/12/88	8 00	12 33	6 92	45	45	106	113	6 12	53	51	163	164	6 86	39	223	239
1/13/88	13 00	13 54	7 10	55	55	106	116	6 29	55	58	167	170	7 17	50	226	240
1/14/88	12 15	14 51	7 09	57	57	108	117	6 32	52	58	167	172	7 22	52	226	244
1/14/88	14 00	14 58	7 08	57	57	108	116	6.33	53	59	167	172	7 22	52	226	243
1/14/88	16 00	14 67	7 08	56	57	108	116	6.33	53	59	167	172	7.23	52	229	243
1/14/88	18 00	14 75	6.64	55	57	107	116	6 20	50	59	166	172	7 05	52	228	243
1/14/88	20 00	14 83	6 50	48	54	104	114	6 03	46	43	166	170	6 60	51	229	243
1/14/88	23 15	14 97	6.46	45	40	104	112	5.58	41	41	156	157	5 92	41	226	237
1/15/88	4 30	15.19	6 58	45	40	105	113	5.83	42	42	156	157	6 22	37	226	238
1/15/88	8 15	15 34	6 65	44	40	104	113	5 92	43	46	157	157	6 52	38	225	238
1/16/88	9 00	16 38	6 55	43	42	104	112	5 71	42	45	156	156	6 12	37	225	237
1/16/88	11 00	16 46	6 55	43	41	105	112	5 76	42	45	157	157	6 17	37	224	237
1/16/88	13 00	16 54	6 57	43	41	105	113	5.81	43	45	157	157	6.27	37	225	238
1/16/88	16 00	16 67	6 61	43	41	105	112	5.86	43	44	158	158	6 42	37	NA	NA
1/16/88	19 00	16 79	6 62	43	41	105	112	5 91	43	46	158	159	6.54	37	NA	NA
1/17/88	8 00	17 33	6 98	47	47	105	113	6.10	51	51	164	166	6.83	42	NA	NA
1/19/88	15 35	19 65	NA	61	60	108	117	NA	61	62	167	173	NA	54	227	244
1/21/88	15 00	21 63	7 30	70	65	110	118	6 55	87	67	168	172	7 50	54	228	246
1/28/88	11 10	28 47	7 90	102	88	NA	NA	6.72	88	78	169	172	7 60	70	237	249
1/30/88	11 20	30 47	7 70	58	53	112	121	6 66	56	75	170	174	7 52	40	NA	241
2/4/88	8 30	35 35	8 11	76	74	116	124	6 73	75	71	169	173	7 58	58	211	246
2/12/88	14 25	43 60	DRY	100	93	122	130	7 03	87	81	171	174	7 60	73	216	252
2/18/88	9 45	49 41	DRY	125	113	124	132	DRY	102	86	173	176	7 69	82	231	254
2/23/88	8 30	54 35	DRY	156	126	126	134	DRY	118	91	175	178	7.72	90	NA	256
3/1/88	9 00	60 38	DRY	72	66	128	135	7 05	59	95	179	182	7 63	55	NA	254
3/10/88	13 50	69 57	DRY	77	98	128	134	DRY	67	84	170	173	DRY	54	218	254
3/19/88	8 30	78 35	DRY	154	134	131	140	DRY	110	92	168	173	DRY	78	220	260

Calculated Data

JULIAN DATE	CUMULATIVE RAINFALL (CM)	WELL A (CM BELOW SURFACE)	TENSIOMETERS (MILLIBARS)				WELL B (CM BELOW SURFACE)	TENSIOMETERS (MILLIBARS)				WELL C (CM BELOW SURFACE)	TENSIOMETERS (MBARS)		
			A1	A2	A4	A5		B1	B2	B4	B5		C2	C4	C5
336.35	22.46	NR	86	NR	64	NR	165.2	56	NR	NR	NR	166.4	30	30	14
336.51	22.58	NR	83	NR	63	NR	167.0	55	132	NR	NR	195.7	32	30	9
336.55	22.71	NR	74	NR	56	NR	161.2	55	110	NR	NR	188.7	27	29	12
336.59	23.24	NR	71	NR	54	NR	156.7	54	93	NR	12	182.3	26	29	12
336.64	23.24	222.5	69	NR	54	NR	154.2	54	73	NR	11	180.1	26	29	11
336.68	25.86	214.9	70	NR	52	NR	156.1	53	53	NR	11	181.1	25	26	11
337.38	25.86	217.9	86	NR	52	7	171.9	57	54	129	14	200.3	42	NR	11
337.42	25.91	218.5	88	NR	50	7	172.2	57	54	126	13	200.3	43	NR	10
337 46	25.93	219.2	88	NR	22	7	172.8	57	56	122	13	200.6	44	18	15
337.50	25.93	220.7	90	NR	23	7	171.9	58	57	120	19	201.2	45	23	15
337.54	25.93	221.9	91	NR	24	8	172.2	54	58	119	13	201.2	46	24	17
337.56	25.93	224.3	91	NR	25	9	172.2	57	58	116	13	201.5	46	24	15
337.67	26.01	NR	93	NR	26	8	171.9	58	60	114	12	203.0	46	22	15
337.71	26.01	NR	95	NR	28	10	172.2	59	60	114	13	201.5	46	25	16
337.79	26.01	NR	97	NR	29	11	173.1	60	60	112	13	202.4	47	25	18
337 86	26.01	NR	99	NR	29	12	174.3	62	62	109	15	203.0	48	25	14
338.00	26.01	NR	108	NR	31	14	174.3	64	62	109	17	204.5	51	27	14
338.10	26.01	221.3	100	NR	26	10	166.7	57	62	108	15	196.0	48	22	13
338.22	28.65	202.7	88	NR	21	6	157.9	51	55	106	11	180.7	42	21	12
338.31	30.00	184.1	75	NR	20	4	147.2	50	49	52	3	161.5	28	20	8
338.37	30.38	182.0	74	NR	18	2	148.7	49	49	51	3	170.7	29	20	8
338.43	30.53	181.4	72	NR	18	2	153.3	49	49	51	1	177.7	32	20	7
338.50	30.84	182.3	70	NR	18	2	157.0	50	49	51	3	181.1	31	16	2
338.68	30.86	185.6	71	NR	15	-1	162.5	53	47	22	6	188 1	36	14	0
338.77	31 14	186.8	71	NR	16	0	164.3	53	49	23	8	189.6	36	14	2
338.84	31.22	188.1	71	NR	15	1	165.5	53	50	23	9	191.4	37	15	1
338.92	31 22	188.4	71	37	16	1	165.8	54	49	22	10	192.6	36	15	1
339.08	31.52	189.9	50	38	18	4	166.4	54	50	23	11	194.5	35	20	6
339.30	31.52	192.6	70	38	18	3	167.3	56	52	23	13	195.7	39	22	5
339.42	31.90	193.5	48	49	20	5	166.4	54	52	23	13	195 4	42	23	5
339.50	32.36	192.6	31	39	19	4	166.7	52	52	23	13	195.1	41	23	5
339 57	32.49	192.6	35	39	19	4	166 4	51	51	23	12	194 5	40	23	6
339.66	32 49	192.0	54	36	19	5	166 1	51	52	23	11	194.8	41	24	7
339.75	32 49	192.3	63	34	18	4	165.5	52	52	23	11	195.1	40	25	9
339.83	32.49	192.0	67	34	18	5	166.1	54	52	23	11	195.1	41	26	10
339 92	32.49	192.3	73	34	18	4	166.1	55	54	23	11	195 7	42	25	12
340.00	32 51	193.2	77	34	18	4	166.7	58	54	22	12	192.0	43	26	12
340.13	33.30	185.0	57	33	13	0	160.9	52	53	22	8	188.7	43	26	12
340.25	34.09	176.2	38	33	12	-1	144.5	44	46	16	0	154 2	38	26	12
340.33	35.74	175 9	38	31	11	-2	135.6	45	46	13	-6	145.4	35	26	12
341 46	40.08	183.8	46	NR	13	-1	158.5	50	46	19	9	184 4	34	22	11
344.52	50.32	177.1	47	NR	11	-3	145 4	47	45	7	-9	154.5	33	18	3
350.65	52 07	192.3	87	36	24	7	164 0	60	70	18	15	197.5	68	42	20
2.63	60.35	192.0	60	50	20	4	165.8	47	63	15	11	196.9	51	22	9
2.71	60.35	192.0	64	62	20	4	165.8	52	63	16	12	196.9	54	28	10
2.79	60 43	192.0	64	64	20	4	165.8	58	63	15	12	196.9	55	30	11
2.92	60 43	192.0	64	64	20	4	165 8	58	63	15	12	196.9	55	30	11
3.00	60.45	191.7	67	67	21	5	165.5	63	65	16	12	197.2	56	32	11
3.13	61.19	192.0	66	67	21	6	165 2	62	65	18	14	196.3	55	33	12
3.42	61.47	192.0	67	68	21	5	164.9	55	65	17	14	196.0	57	33	12
3.56	61.60	190.8	65	67	22	6	164.0	54	65	17	14	195.7	57	33	11
7.50	62.23	196.6	69	69	24	7	168.2	64	67	18	14	199.6	62	36	17
10.46	68.36	184.1	45	46	16	0	157.0	50	49	18	11	184.1	38	27	11
11.40	72.26	175.0	43	42	14	-2	152 7	46	49	12	2	175 3	39	27	11
12.33	73.28	184.4	45	45	16	-1	154.5	53	51	14	5	180.1	39	27	11
13.54	73.84	189.9	55	55	16	2	159.7	55	58	18	11	189.6	50	30	12
14.51	74.45	189 6	57	57	18	3	160.6	52	58	18	13	191.1	52	30	16
14.58	74.45	189.3	57	57	18	2	160.9	53	59	18	13	191.1	52	30	15
14.67	74.47	189.3	56	57	18	2	160.9	53	59	18	13	191.4	52	33	15
14.75	74.47	175.9	55	57	17	2	157.0	50	59	17	13	185.9	52	32	15
14.83	74.47	171.6	48	54	14	0	151.8	46	43	17	11	172 2	51	33	15
14.97	78.28	170.4	45	40	14	-2	138 1	41	41	7	-2	151.5	41	30	9
15.19	78.87	174.0	45	40	15	-1	145.7	42	42	7	-2	160.6	37	30	10
15.34	78 67	176.2	44	40	14	-1	148.4	43	46	8	-2	169 8	38	29	10
16.38	81.97	173.1	43	42	14	-2	142 0	42	45	7	-3	157 6	37	29	9
16.46	81.97	173.1	43	41	15	-2	143.6	42	45	8	-2	159 1	37	28	9
16.54	81.97	173.7	43	41	15	-1	145.1	43	45	8	-2	162.2	37	29	10
16.67	82.65	175.0	43	41	15	-2	146.6	43	44	9	-1	166 7	37	NR	NR
16.79	82.65	175.3	43	41	15	-2	148.1	43	46	9	0	170.4	37	NR	NR
17.33	82.65	186.2	47	47	15	-1	153.9	51	51	15	7	179 2	42	NR	NR
19.65	83.01	NR	61	60	16	3	NR	61	62	16	14	NR	54	31	16
21.63	83.03	196.0	70	65	20	4	167.6	67	67	19	13	199.6	54	32	18
28.47	83.24	214.3	102	88	NR	NR	172.8	88	78	20	13	202.7	70	41	21
30.47	86.31	208.2	58	53	22	7	171.0	56	75	21	15	200.3	40	NR	13
35.35	66.64	220.7	76	74	26	10	173.1	75	71	20	14	202 1	58	15	16
43.60	87.45	NR	100	93	32	16	182.3	87	81	22	15	202.7	73	20	24
49.41	87.45	NR	125	113	34	18	NR	102	86	24	17	205 4	82	35	26
54.35	87.50	NR	156	126	36	20	NR	118	91	26	19	206.3	89	NR	28
60.38	87.53	NR	72	66	36	21	162.9	59	95	30	23	203.6	55	NR	26
69.57	92.63	NR	77	98	38	20	NR	67	84	21	14	NR	54	22	26
78.35	92.71	NR	154	134	41	26	NR	110	92	19	14	NR	78	24	32

Degree Saturation

DATE	TIME	JULIAN DATE	A1	A2	A4	A5	B1	B2	B4	B5	C2	C4	C5
			TENSION CONVERTED TO DEGREE OF SATURATION										
12/2/87	8:23	336.35	0.42	NA	0.71	NA	0.49	NA	NA	NA	0.63	0.80	0.89
12/2/87	12.15	336.51	0.42	NA	0.71	NA	0.49	0.42	NA	NA	0.62	0.80	0.92
12/2/87	13:15	336.55	0.44	NA	0.72	NA	0.49	0.44	NA	NA	0.64	0.80	0.90
12/2/87	14:15	336.59	0.44	NA	0.73	NA	0.50	0.46	NA	0.90	0.64	0.80	0.90
12/2/87	15:15	336.64	0.45	NA	0.73	NA	0.50	0.50	NA	0.90	0.64	0.80	0.90
12/2/87	16:15	336.68	0.45	NA	0.73	NA	0.50	0.55	NA	0.90	0.65	0.82	0.90
12/3/87	9:00	337.38	0.42	NA	0.73	0.93	0.49	0.55	0.77	0.89	0.59	0.89	0.90
12/3/87	10.00	337.42	0.42	NA	0.74	0.93	0.49	0.55	0.76	0.89	0.58	0.90	0.91
12/3/87	11:00	337.46	0.42	NA	0.83	0.93	0.49	0.54	0.75	0.89	0.58	0.85	0.88
12/3/87	12:00	337.50	0.42	NA	0.83	0.93	0.48	0.54	0.75	0.86	0.58	0.83	0.88
12/3/87	13:00	337.54	0.42	NA	0.82	0.92	0.50	0.54	0.74	0.89	0.57	0.82	0.87
12/3/87	14:00	337.58	0.42	NA	0.82	0.92	0.49	0.54	0.74	0.89	0.57	0.82	0.88
12/3/87	16:00	337.67	0.42	NA	0.82	0.92	0.48	0.53	0.73	0.90	0.57	0.83	0.88
12/3/87	17:00	337.71	0.41	NA	0.81	0.91	0.48	0.53	0.73	0.89	0.57	0.82	0.88
12/3/87	19:00	337.79	0.41	NA	0.80	0.90	0.48	0.53	0.73	0.89	0.57	0.82	0.87
12/3/87	21:00	337.88	0.42	NA	0.80	0.90	0.47	0.52	0.72	0.88	0.57	0.82	0.89
12/4/87	0:01	338.00	NA	NA	0.80	0.89	0.46	0.52	0.72	0.87	0.56	0.81	0.89
12/4/87	2:30	338.10	0.42	NA	0.82	0.91	0.49	0.52	0.72	0.88	0.57	0.83	0.89
12/4/87	5:10	338.22	0.42	NA	0.84	0.93	0.51	0.54	0.72	0.90	0.59	0.84	0.90
12/4/87	7:30	338.31	0.44	NA	0.84	0.95	0.51	0.56	0.73	0.95	0.63	0.84	0.92
12/4/87	8:50	338.37	0.44	NA	0.85	0.96	0.52	0.56	0.73	0.95	0.63	0.84	0.92
12/4/87	10:15	338.43	0.44	NA	0.85	0.96	0.52	0.56	0.73	0.96	0.62	0.84	0.93
12/4/87	12.05	338.50	0.45	NA	0.85	0.96	0.51	0.56	0.73	0.95	0.62	0.86	0.96
12/4/87	16:15	338.68	0.44	NA	0.87	0.98	0.50	0.57	0.83	0.93	0.61	0.87	0.97
12/4/87	18.30	338.77	0.44	NA	0.86	0.97	0.50	0.56	0.83	0.92	0.61	0.87	0.96
12/4/87	20:15	338.84	0.44	NA	0.87	0.96	0.50	0.56	0.83	0.92	0.60	0.87	0.96
12/4/87	22:00	338.92	0.44	0.60	0.86	0.96	0.50	0.56	0.83	0.91	0.61	0.87	0.96
12/5/87	2:00	339.08	0.51	0.60	0.85	0.95	0.50	0.56	0.83	0.90	0.61	0.84	0.93
12/5/87	7:15	339.30	0.45	0.60	0.85	0.95	0.49	0.55	0.83	0.89	0.60	0.83	0.94
12/5/87	10:00	339.42	0.52	0.56	0.84	0.94	0.50	0.55	0.83	0.89	0.59	0.83	0.94
12/5/87	12:00	339.50	0.61	0.60	0.85	0.95	0.51	0.55	0.83	0.89	0.59	0.83	0.94
12/5/87	13:40	339.57	0.59	0.60	0.85	0.95	0.51	0.55	0.83	0.90	0.59	0.83	0.93
12/5/87	15:50	339.66	0.50	0.61	0.85	0.94	0.51	0.55	0.83	0.90	0.59	0.82	0.93
12/5/87	18.00	339.75	0.47	0.61	0.85	0.95	0.51	0.55	0.83	0.90	0.59	0.82	0.92
12/5/87	20:00	339.83	0.45	0.61	0.85	0.94	0.50	0.55	0.83	0.90	0.59	0.82	0.91
12/5/87	22:00	339.92	0.44	0.61	0.85	0.95	0.49	0.55	0.83	0.90	0.59	0.82	0.90
12/6/87	0.01	340.00	0.43	0.61	0.85	0.95	0.48	0.55	0.83	0.90	0.58	0.82	0.90
12/6/87	3:00	340.13	0.49	0.62	0.88	0.97	0.51	0.55	0.83	0.92	0.58	0.82	0.90
12/6/87	6:00	340.25	0.57	0.62	0.88	0.98	0.54	0.57	0.86	0.97	0.60	0.82	0.90
12/6/87	8:00	340.33	0.58	0.62	0.89	0.98	0.54	0.57	0.88	1.01	0.61	0.82	0.90
12/7/87	11:00	341.46	0.53	NA	0.88	0.98	0.51	0.57	0.85	0.92	0.61	0.83	0.90
12/10/87	12.30	344.52	0.53	NA	0.89	0.99	0.53	0.57	0.91	1.03	0.62	0.85	0.95
12/16/87	15.30	350.65	0.42	0.61	0.82	0.93	0.48	0.50	0.85	0.88	0.51	0.76	0.86
1/2/88	15:00	2.63	0.48	0.56	0.84	0.95	0.53	0.52	0.87	0.90	0.56	0.83	0.92
1/2/88	17:00	2.71	0.46	0.53	0.84	0.95	0.51	0.52	0.86	0.90	0.55	0.81	0.91
1/2/88	19:00	2.79	0.46	0.52	0.84	0.95	0.48	0.52	0.87	0.90	0.55	0.80	0.90
1/2/88	22:00	2.92	0.46	0.52	0.84	0.95	0.48	0.52	0.87	0.90	0.55	0.80	0.90
1/3/88	0:01	3.00	0.45	0.52	0.84	0.94	0.47	0.52	0.86	0.90	0.54	0.79	0.90
1/3/88	3:00	3.13	0.46	0.52	0.84	0.93	0.47	0.52	0.85	0.89	0.55	0.79	0.90
1/3/88	10:00	3.42	0.45	0.51	0.84	0.94	0.49	0.52	0.86	0.89	0.54	0.79	0.90
1/3/88	13.30	3.56	0.46	0.52	0.83	0.93	0.50	0.52	0.86	0.89	0.54	0.79	0.90
1/7/88	12:00	7.50	0.45	0.51	0.82	0.93	0.46	0.51	0.85	0.89	0.53	0.78	0.87
1/10/88	11.30	10.48	0.54	0.57	0.86	0.97	0.51	0.56	0.85	0.90	0.60	0.81	0.90
1/11/88	9:40	11.40	0.55	0.59	0.87	0.98	0.53	0.56	0.88	0.96	0.60	0.81	0.90
1/12/88	8:00	12.33	0.54	0.58	0.86	0.98	0.50	0.55	0.87	0.94	0.60	0.81	0.90
1/13/88	13:00	13.54	0.49	0.55	0.86	0.96	0.49	0.54	0.85	0.90	0.56	0.80	0.90
1/14/88	12.15	14.51	0.49	0.54	0.85	0.95	0.51	0.54	0.85	0.89	0.56	0.80	0.88
1/14/88	14:00	14.58	0.49	0.54	0.85	0.96	0.50	0.53	0.85	0.89	0.56	0.80	0.88
1/14/88	16:00	14.87	0.49	0.54	0.85	0.96	0.50	0.53	0.85	0.89	0.56	0.79	0.88
1/14/88	18:00	14.75	0.49	0.54	0.86	0.96	0.51	0.53	0.86	0.89	0.56	0.79	0.88
1/14/88	20:00	14.83	0.52	0.55	0.87	0.97	0.53	0.58	0.86	0.90	0.56	0.79	0.88
1/14/88	23.15	14.97	0.54	0.59	0.87	0.98	0.56	0.59	0.91	0.98	0.59	0.80	0.92
1/15/88	4:30	15.19	0.54	0.59	0.87	0.98	0.55	0.58	0.91	0.98	0.60	0.80	0.91
1/15/88	8:15	15.34	0.54	0.59	0.87	0.98	0.55	0.57	0.90	0.98	0.60	0.80	0.91
1/16/88	9.00	16.38	0.55	0.59	0.87	0.98	0.55	0.57	0.91	0.99	0.60	0.80	0.92
1/16/88	11.00	16.48	0.55	0.59	0.87	0.98	0.55	0.57	0.90	0.98	0.60	0.81	0.92
1/16/88	13:00	16.54	0.55	0.59	0.87	0.98	0.55	0.57	0.90	0.98	0.60	0.80	0.91
1/16/88	16.00	16.67	0.55	0.59	0.87	0.98	0.55	0.58	0.90	0.98	0.60	NA	NA
1/16/88	19:00	16.79	0.55	0.59	0.87	0.98	0.55	0.57	0.90	0.97	0.60	NA	NA
1/17/88	8:00	17.33	0.53	0.57	0.87	0.98	0.51	0.55	0.87	0.93	0.59	NA	NA
1/19/88	15:35	19.65	0.47	0.53	0.85	0.95	0.47	0.52	0.85	0.89	0.55	0.80	0.88
1/21/88	15:00	21.63	0.45	0.52	0.84	0.95	0.45	0.51	0.85	0.89	0.55	0.79	0.87
1/28/88	11:10	28.47	0.42	0.47	NA	NA	0.42	0.49	0.84	0.89	0.51	0.76	0.85
1/30/88	11.20	30.47	0.48	0.55	0.83	0.93	0.49	0.49	0.84	0.88	0.59	NA	0.89
2/4/88	8:30	35.35	0.43	0.50	0.82	0.91	0.44	0.50	0.84	0.89	0.54	0.87	0.87
2/12/88	14:25	43.60	0.42	0.46	0.79	0.88	0.42	0.48	0.83	0.88	0.50	0.84	0.84
2/18/88	9:45	49.41	0.45	0.44	0.78	0.87	0.42	0.47	0.82	0.87	0.48	0.78	0.83
2/23/88	8:30	54.35	0.58	0.43	0.78	0.86	0.44	0.46	0.82	0.86	0.47	NA	0.82
3/1/88	9:00	60.38	0.44	0.52	0.77	0.85	0.48	0.46	0.80	0.84	0.55	NA	0.83
3/10/88	13.50	69.57	0.43	0.46	0.77	0.86	0.45	0.48	0.84	0.89	0.55	0.83	0.83
3/19/88	8:30	78.35	0.57	0.42	0.76	0.83	0.42	0.46	0.85	0.89	0.49	0.82	0.80

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